SPARC DA Workshop

Derivation of wind fields from stratospheric trace gas observations

Frank Baier (DLR), Hendrik Elbern (RIU)

Data provided by:
Fabrice Duruisseau and Nathalie Huret,
LPC2E/CNRS and Orléans University
MIPAS ESA team

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Outline

- ARISE project
- Approach
- Skill analysis
- Species analysis
- Kiruna comparisons

ARISE project

- EU FP7/H2020 Collaborative Infrastructure Design Study
- Phase 1: 2012-2014; phase 2: 2015-2018
- Lead: CEA
- Middle Atmosphere: Linking models and observations

ARISE consortium : Partner's and member's logos

cea	DLR	LATMOS	BGR
University of Reading	STUDIORUM UNIVERSITAS FLORENTINA	KNMI	NORSAR
ÚFA AVČR	IRF	BIRA-IASB aeronomie.be	ÉCOLE CENTRALE LYON

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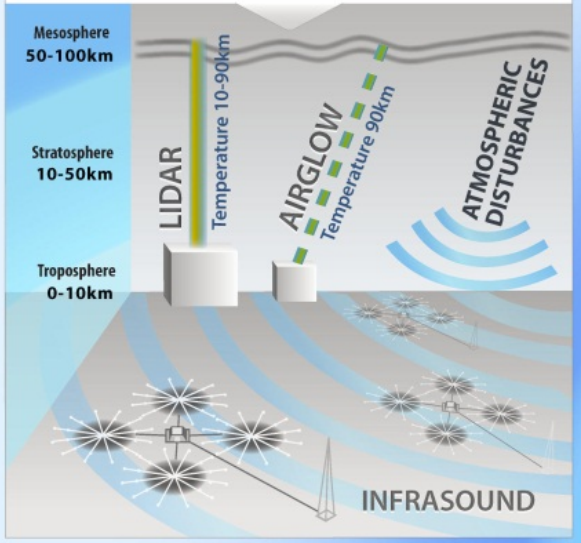
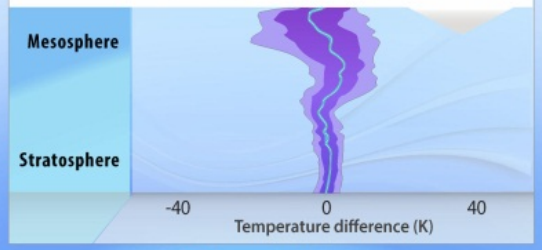
ARISE middle atmospheric dynamics - linking observations and models

ARISE MEASUREMENT STATION
OBSERVATIONS ON MULTIPLE SCALES

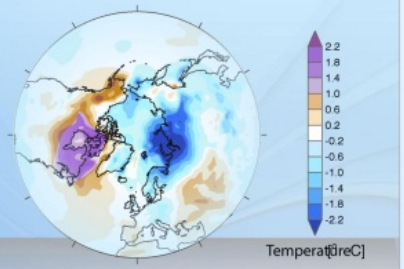


WEATHER MODEL UNCERTAINTY ESTIMATION

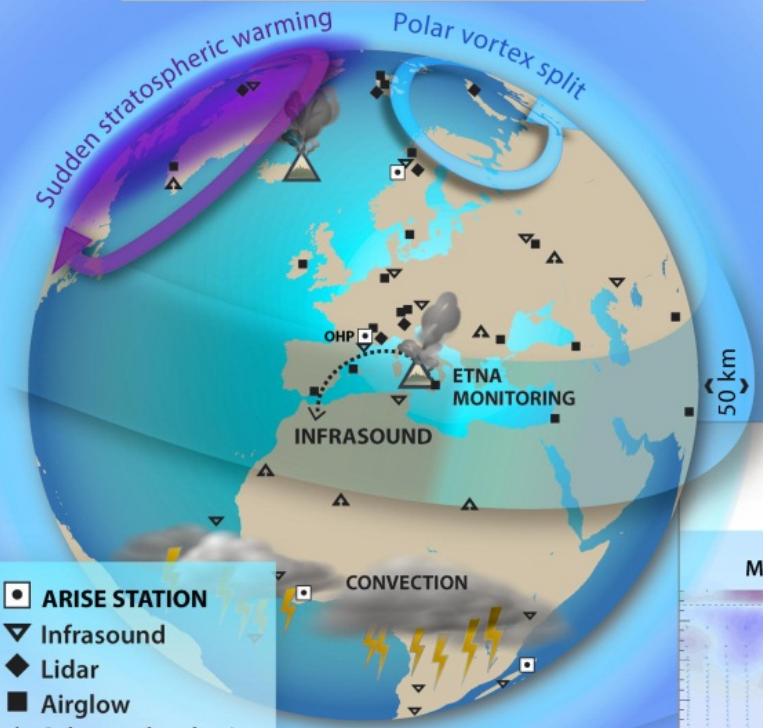


ARISE MODELING
HIGH PERFORMANCE COMPUTING

TOWARDS WEATHER FORECAST IMPROVEMENT

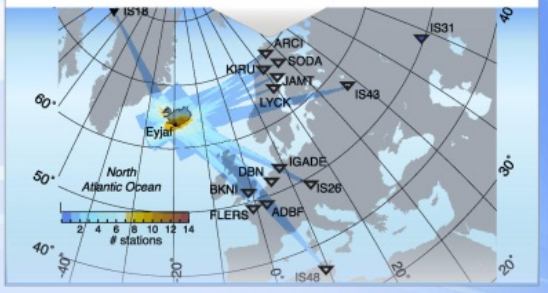


Weather change 20 days following a Sudden Stratospheric Warming



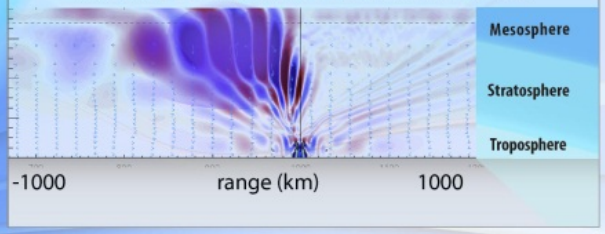
- ARISE STATION
- Infrasound
- Lidar
- Airglow
- Other technologies (radar, satellite)

(long range) VOLCANO MONITORING



HIGH RESOLUTION ATMOSPHERIC DYNAMICS SIMULATION

Modeling gravity waves due to thunderstorms

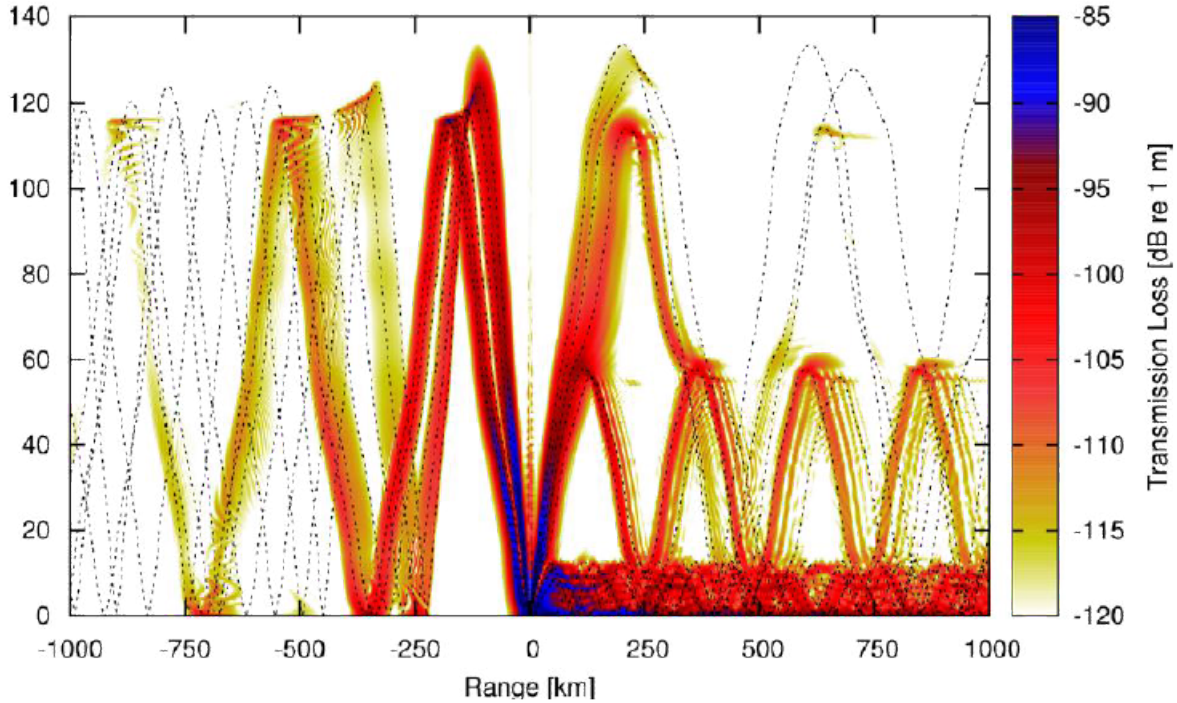


AVAILABLE TO PUBLIC

arise-project.eu

ARISE inversion methods: infrasound propagation

@Le Pichon et al., 2014



Typical IS propagation during boreal winter with wave guides near the Termopause, Stratopause and Tropopause

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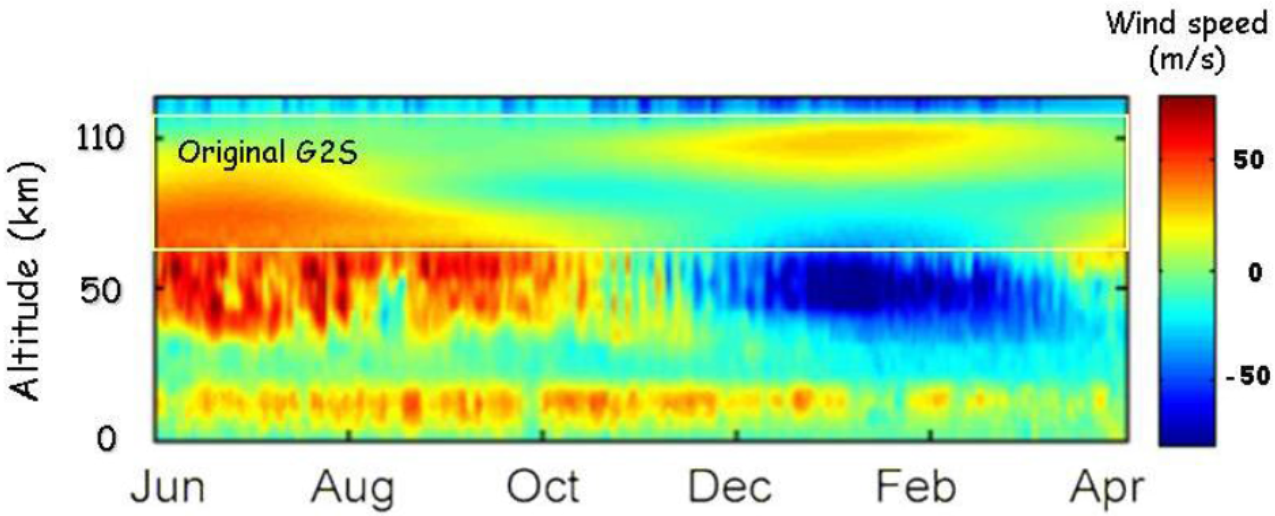
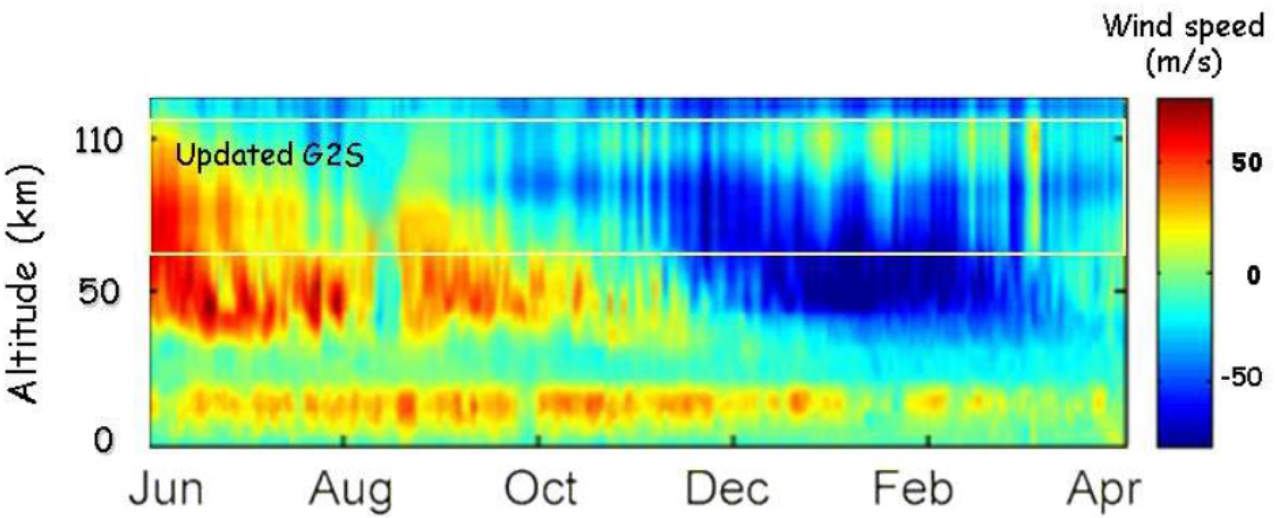
ARISE: reconstruction of upper stratospheric winds



climatology

@Le Pichon et al., 2014



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Derivation of winds from trace gas observations

- Daley, 1995: 1-dimensional Kalman-Filter tracer experiments
- Grandpré, 2007: 4Dvar assimilation of chemical constituents
- Seman et al., 2009: O3 profile assimilation with Méteo-France 4Dvar NWP OP-suite

This study

- 2D isentropic model to study stratospheric winds from tracer inversion
- GME-SACADA coupled model (Elbern et al., 2010) with new adjoint for advection scheme: global study with MIPAS observations
- Comparisons to local wind soundings: Kiruna radiosonde station

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What can be expected?

- 2D-isentropic (const. wind) tracer model experiments:
  - 3h-lagged GME winds for Feb 1st, 2003
  - run isentropic model on 475K level with MIPAS-SACADA O3 tracer
  - compare 24h wind errors w. and wo. lag (skill loss)
  - calculate recover of initial winds with 6h inversion (inv. score)

RMS (Root Mean Squared) wind error scoring

Wind distortion	$du = u(perfect) - u(distorted)$
rms wind error	$\text{rms} = \sqrt{\frac{1}{N}\sum(du_i{}^2 + dv_i{}^2)}$
24h forecast skill (GME' with 3h-lagged winds)	$\text{fsk} = 1 - \frac{rms(GME' - ECMWF)}{rms(GME - ECMWF)}$
6h inversion score	$\text{isc} = 1 - \frac{rms(initial\ winds\ after\ inversion)}{rms(initial\ winds\ before\ inversion)}$

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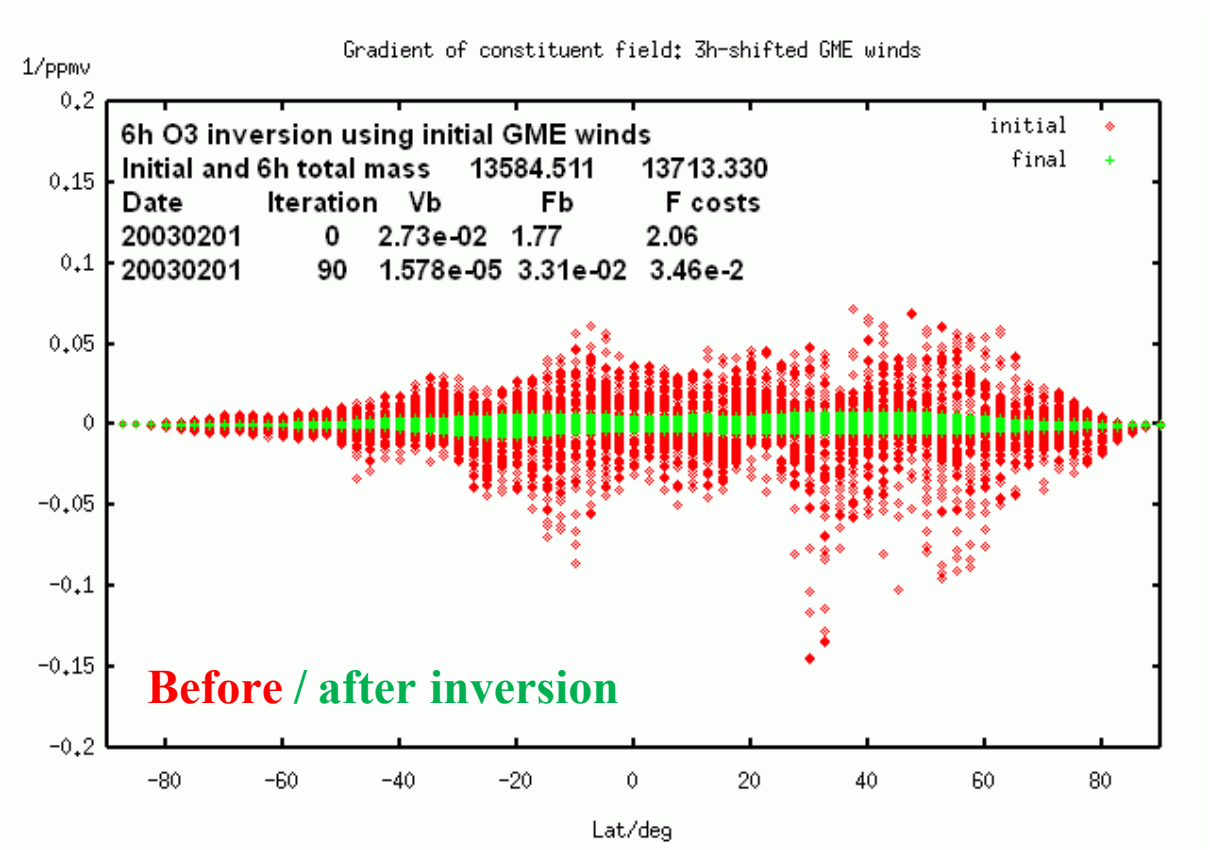
What can be expected?



Test shows that initial wind can be retrieved

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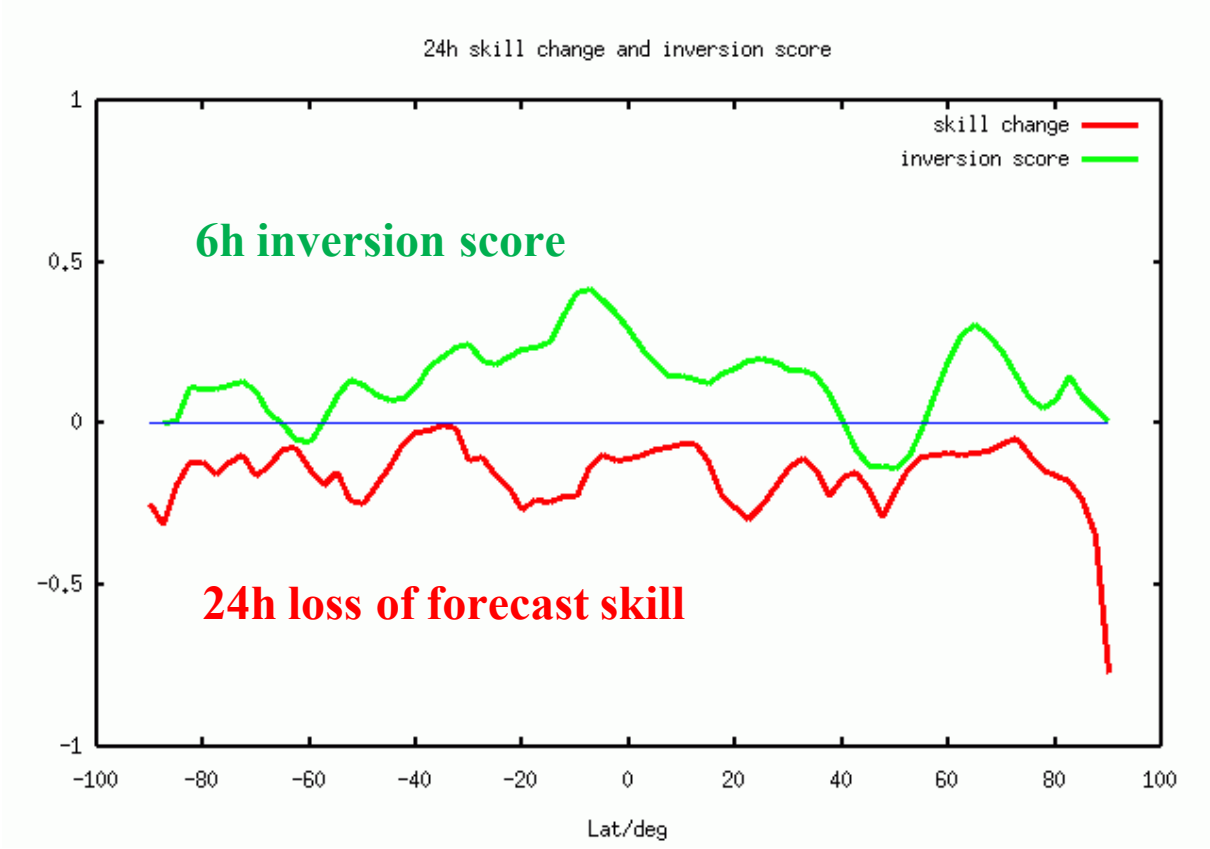
What can be expected?



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Summary isentropic 475K model

- Experiments with MIPAS O3, CH4 and N2O for Feb. 2003 show
- Inversion works best for low and high latitudes
- Only weak differences between species

- Results comply with Seman, Grandpré et al.

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GME-SACADA 4D-Var assimilation system

- GME
  - German global forecasting system 0-60 km altitude (42 levels)
  - icosahedral grid: ~250 km grid spacing
- SACADA
  - full stratospheric transport-chemistry scheme with adjoint
  - *New: adjoint of advection w.r.t. initial wind field*
- 4Dvar scheme
  - Weaver & Courtier incremental background-cov. modelling with
  - Horizontal and vertical lengthscales = 600 km, 3 km

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Calculating wind-gradient of tracer cost function

$$\delta \boldsymbol{x} \equiv \boldsymbol{x} - \boldsymbol{x}_b \,;\; \delta \boldsymbol{x} \equiv H_{adv} \delta \boldsymbol{u} \,;\; \boldsymbol{d} \equiv \boldsymbol{y}^o - H\boldsymbol{x}_b \,;\; \widetilde{H} \equiv H \cdot H_{adv}$$

$$J(\delta \boldsymbol{u}) = \frac{1}{2} \delta \boldsymbol{u}^T B^{-1} \delta \boldsymbol{u} + \frac{1}{2} \left(\widetilde{H} \delta \boldsymbol{u} - \boldsymbol{d} \right)^T R^{-1} \left(\widetilde{H} \delta \boldsymbol{u} - \boldsymbol{d} \right)$$

$$\square := B^{-1/2} \delta \boldsymbol{u} \Rightarrow \delta \boldsymbol{u} = B^{1/2} \square \qquad \text{(Weaver, Courtier 2001)}$$

$$\nabla_{\delta \boldsymbol{u}} J = \nabla_{\delta \boldsymbol{u}} J_b + \nabla_{\delta \boldsymbol{u}} J_o = \square + B^{T/2} \nabla_{\delta \boldsymbol{x}} J_o$$

$$\nabla_{\delta x} J_o = \widetilde{H}^T R^{-1} \left(\widetilde{H} \delta u - d \right) = H_{adv}{}^T H^T R^{-1} (H \delta x - d)$$

Initial gradient does not depend on background!

Advection operator and gradient of cost function

Semi-Lagrange first-order

Diagnostic Euler-upward

$$vmr_n = H_{adv}(vmr_{n-1}) = H_{hor} \circ H_{vert}\,(vmr_{n-1})$$

$$\nabla_{\delta x} J_o = \widetilde{H}^T R^{-1}\left(\widetilde{H}\delta u - d\right) = H_{adv}{}^T H^T R^{-1}(H\delta x - d)$$

adjoint

Inversion experiments Feb. 2003

- MIPAS (ESA): H2O, HNO3, N2O, O3, CH4
- 6h assimilation window (max 15 iterations): 10% wind and vmr errors
- derive new initial wind field for next GME-SACADA fwd run cycle
- assess global cost function (FMOs) w. and wo. Inversion

Meteo Februar northern stratosphere: SSW with vortex spilt in second half.

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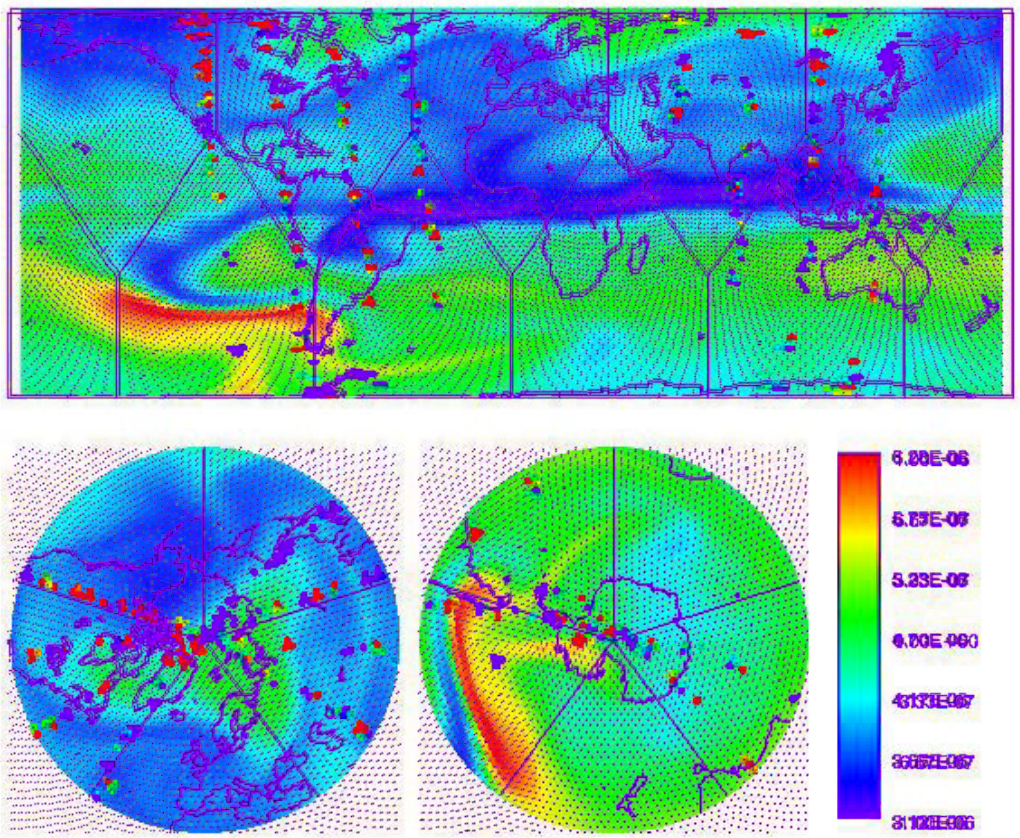
Sample 20 km H2O field from MIPAS analysis



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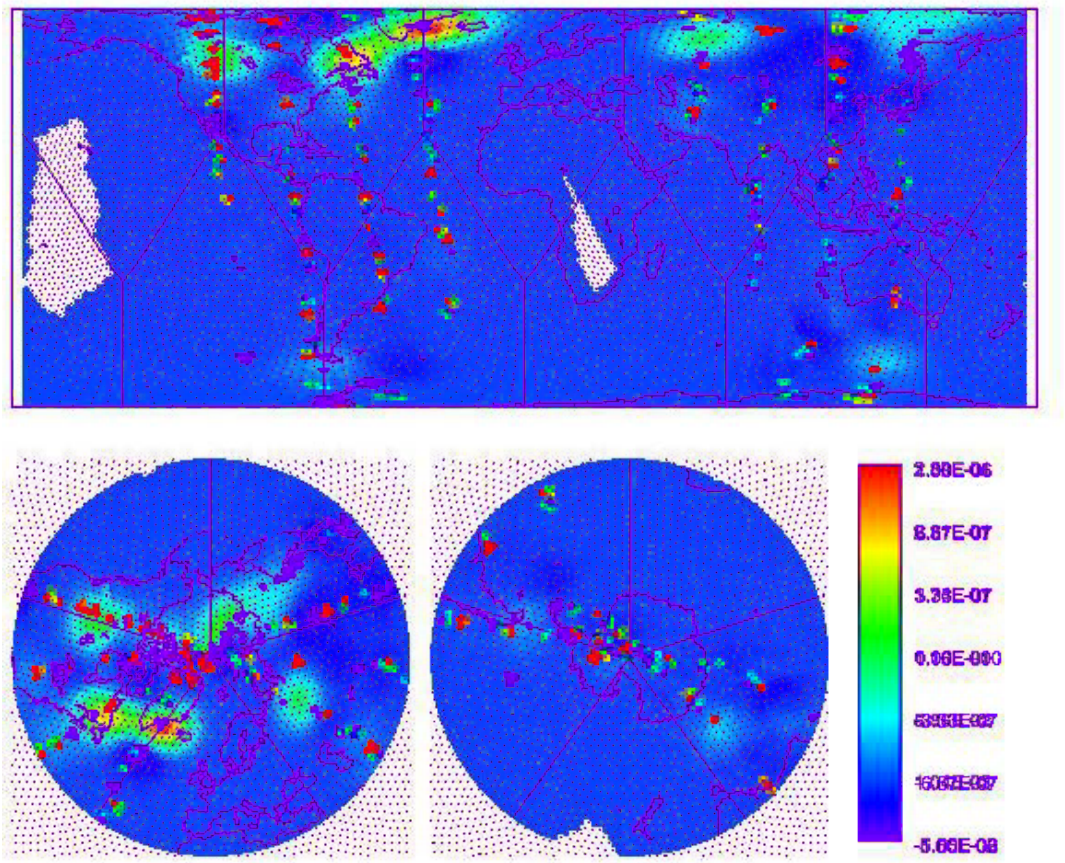
Correction of initial wind field



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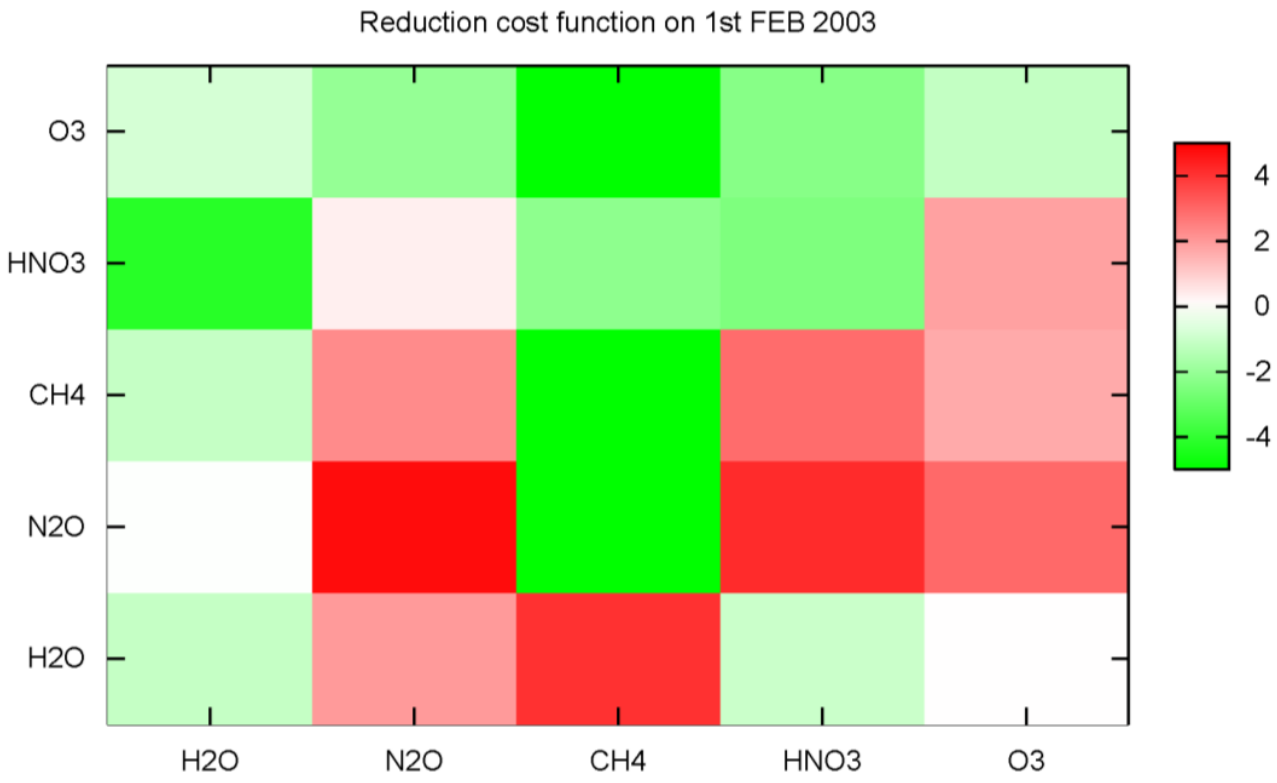
Sensitivity study for different MIPAS trace gases



Reduction of cost function on 1st February, 2003: Y-axis shows assimilated species; X-axis shows species cost function. Note different scaling factors: O3= 2.e2; HNO3= 2.e7; CH4= 1.e4; N2O= 5.e4; H2O= 1.

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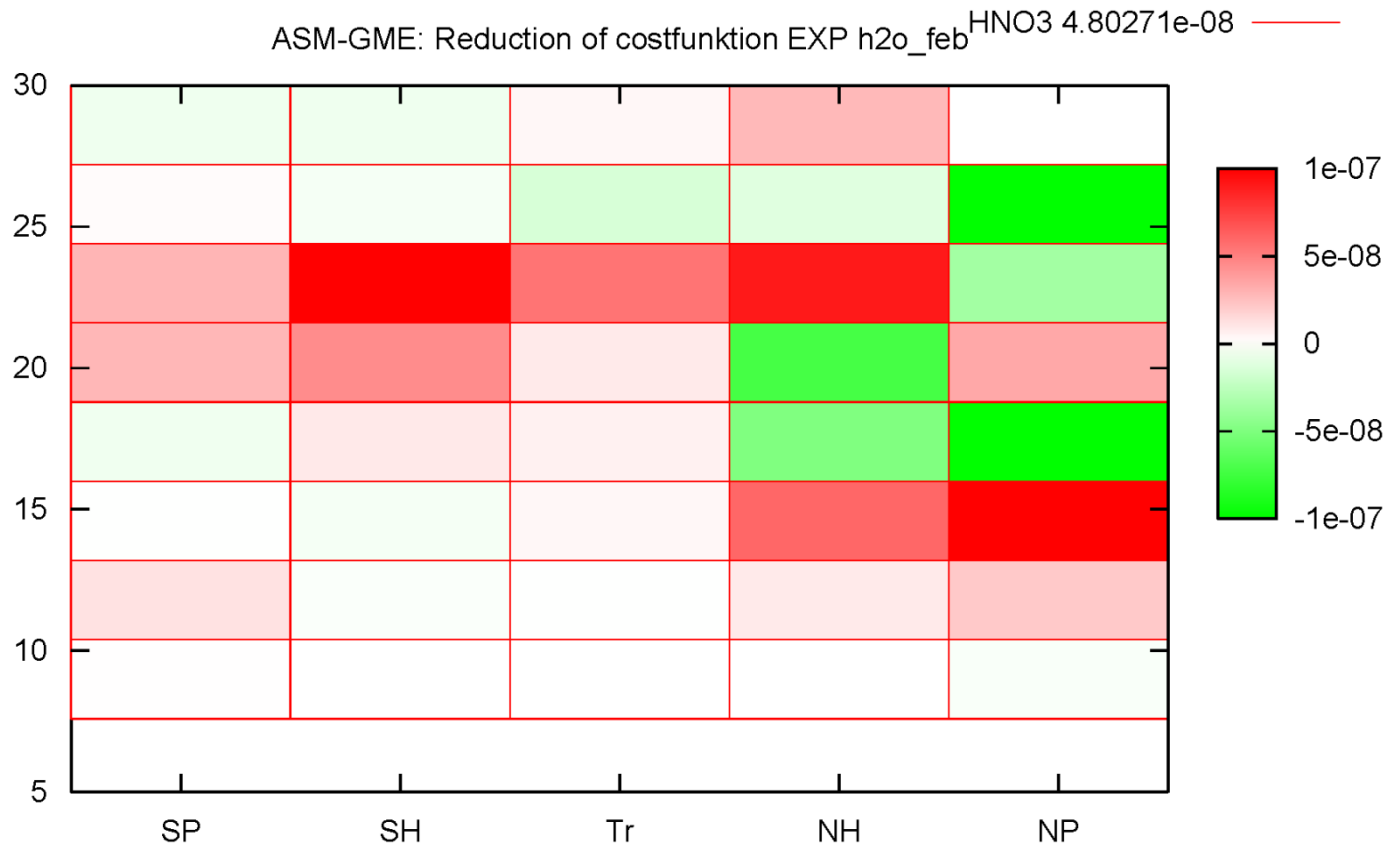
Reduction of cost function: HNO3 Feb. 2003



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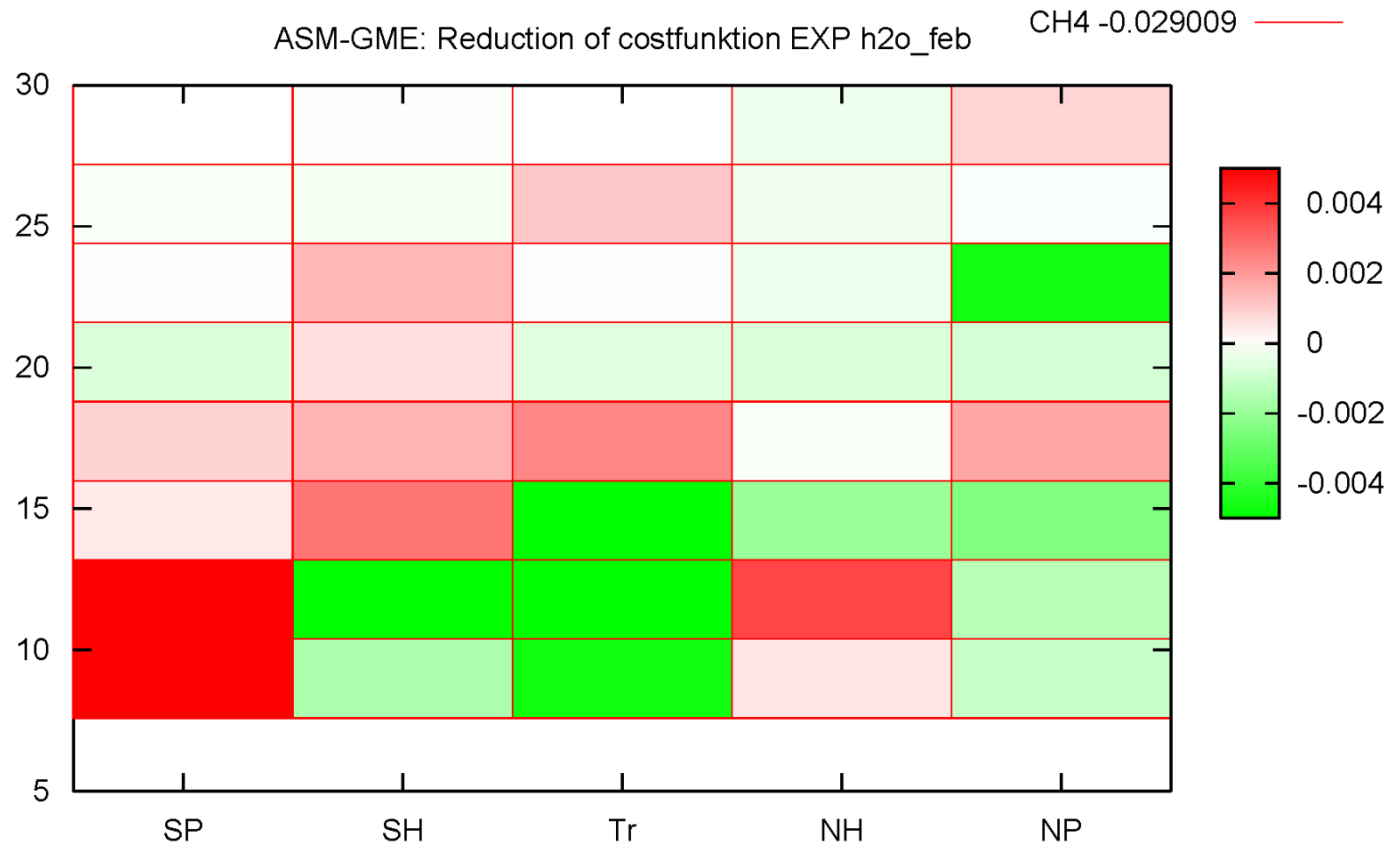
Reduction of cost function: CH4 Feb. 2003



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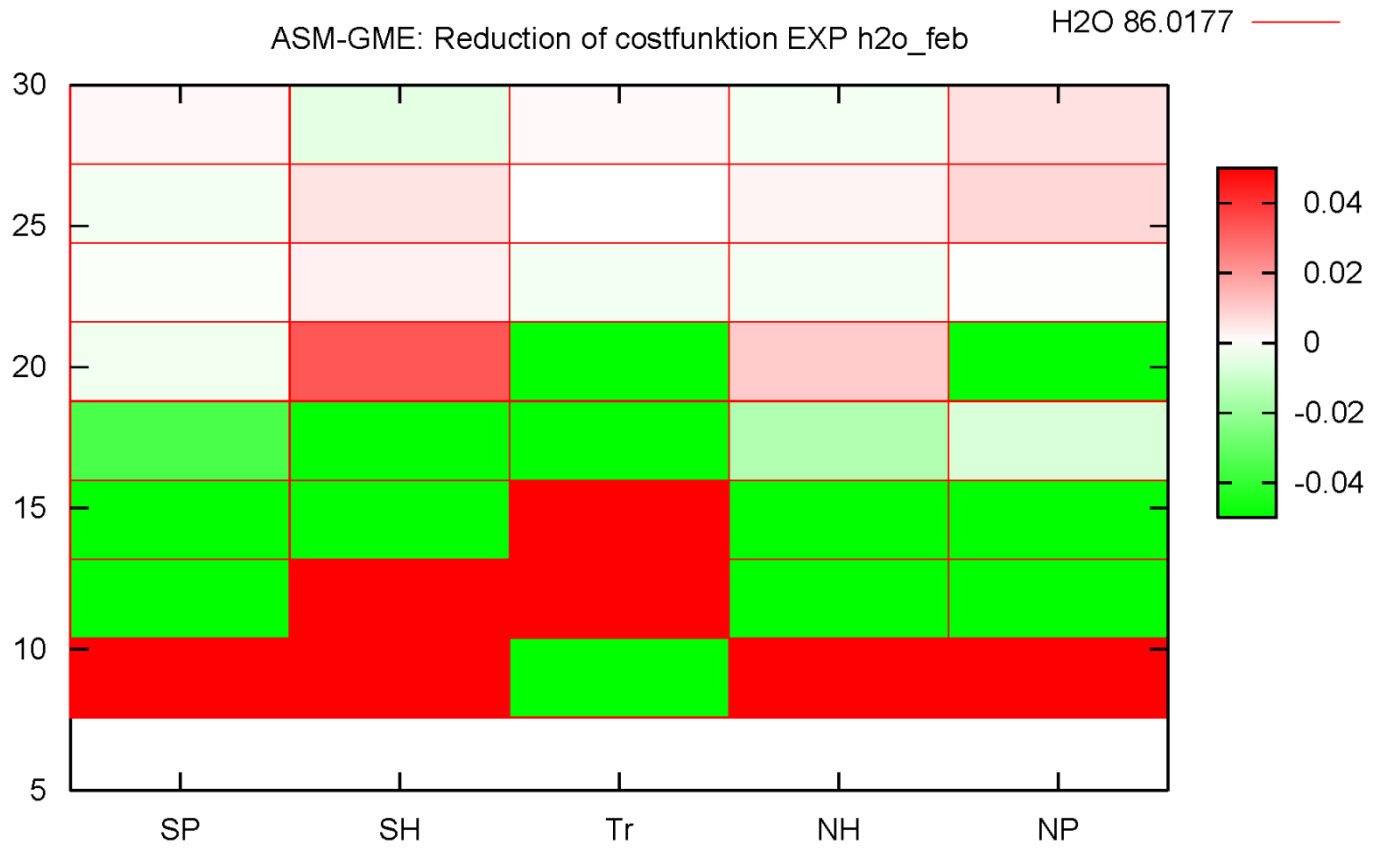
Reduction of cost function: H2O Feb. 2003



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Summary GME-SACADA experiments Feb. 2003

- results are not conclusive (cost function versus wind corrections)
- missing global convergence on some days
- tendency for vertical oscillations – why?
- covariance modelling too coarse? Error in inversion model?

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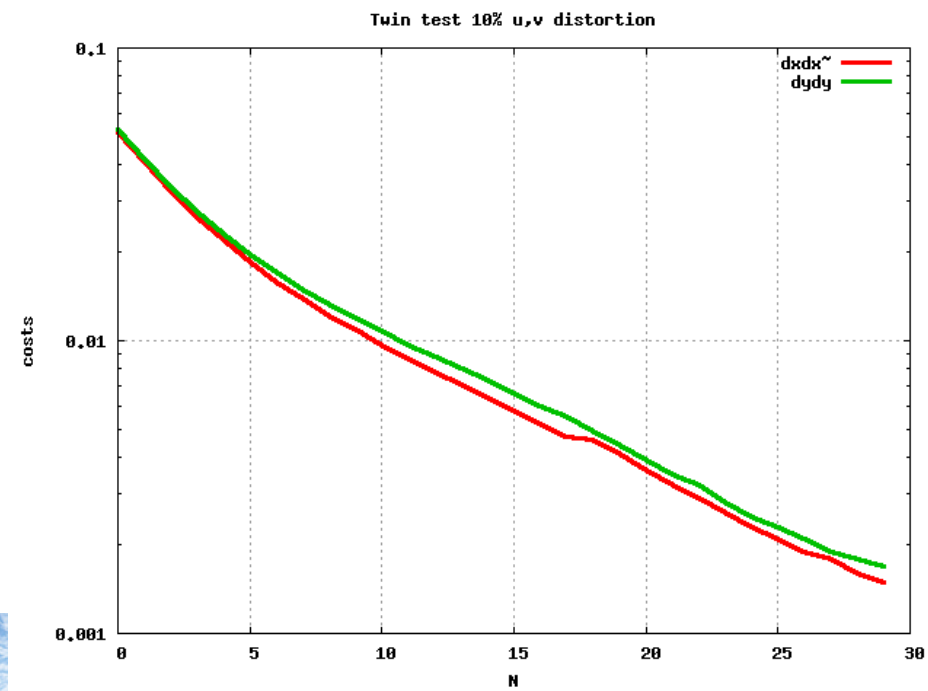
Offline assimilation experiments March 2003

- First-guess winds from GME (=constant)
- MIPAS-SACADA analysis as tracer first-guess
- 6h assimilation window, no background in cost function
- Single processing unit for comparison with Kiruna soundings
- No background in cost function

Dot-product test for twin experiment:

$$\delta x \delta x' \equiv \delta y \delta y$$



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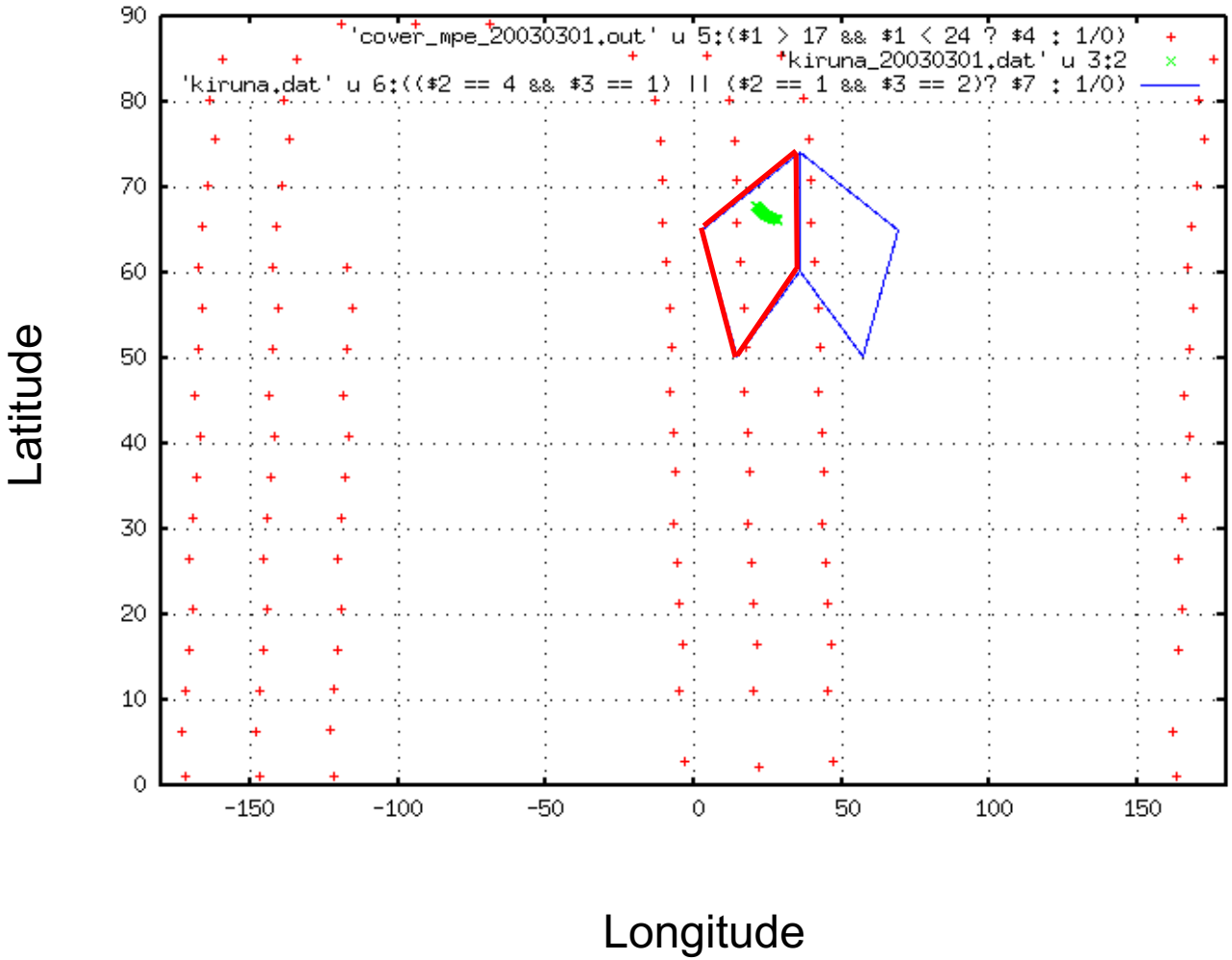
MIPAS trace gas observations and Kiruna soundings within 6h window



GME processing Element

Kiruna @ 67.9° N 21.1° E

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Detailed analysis of winds by Kiruna soundings

- CNRS Kiruna GPS radiosondes
  - 0 – 30 km altitude level
  - Flight time 6 – 9 h (dismiss drop period)
  - 8 soundings in March 2003

Date	Start time	Stop time	Assim. window	
2003-03-01	18:20	23:59	18-24h	★
2003-03-04	12.53	17:30	12-18h	
2003-03-06	05:54	11:02	06-12h	★
2003-03-20	18:14	09:39 (day after)	18-24h	★
2003-03-23	14:12	18:11	12-18h	
2003-03-25	08:57	11:19	06-12h	★
2003-03-30	15:27	18:50	12-18h	
2003-03-31	23:39	04:38 (day after)	18-24h	★

MIPAS coverage

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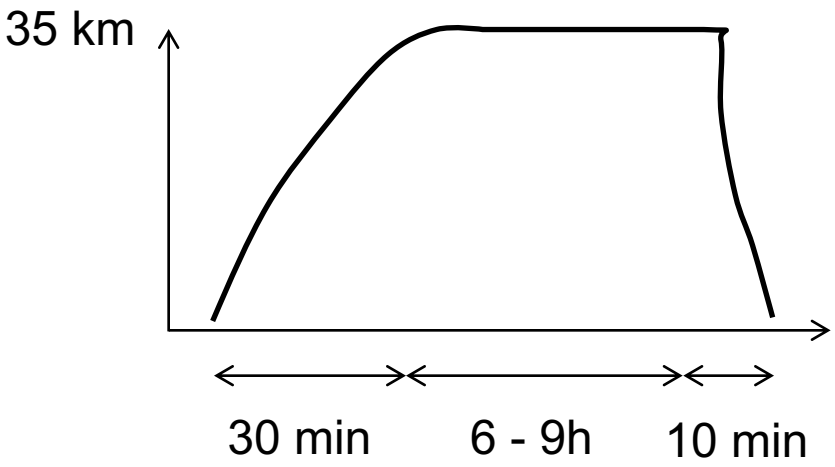
Detailed analysis of winds by Kiruna soundings

- H-operators
  - Binning of MIPAS w.r.t. model g.p. and time (4D trajectory)
  - Binning of (stationary) Kiruna flight-profile (3D trajectory)

Typical sonde flight profile



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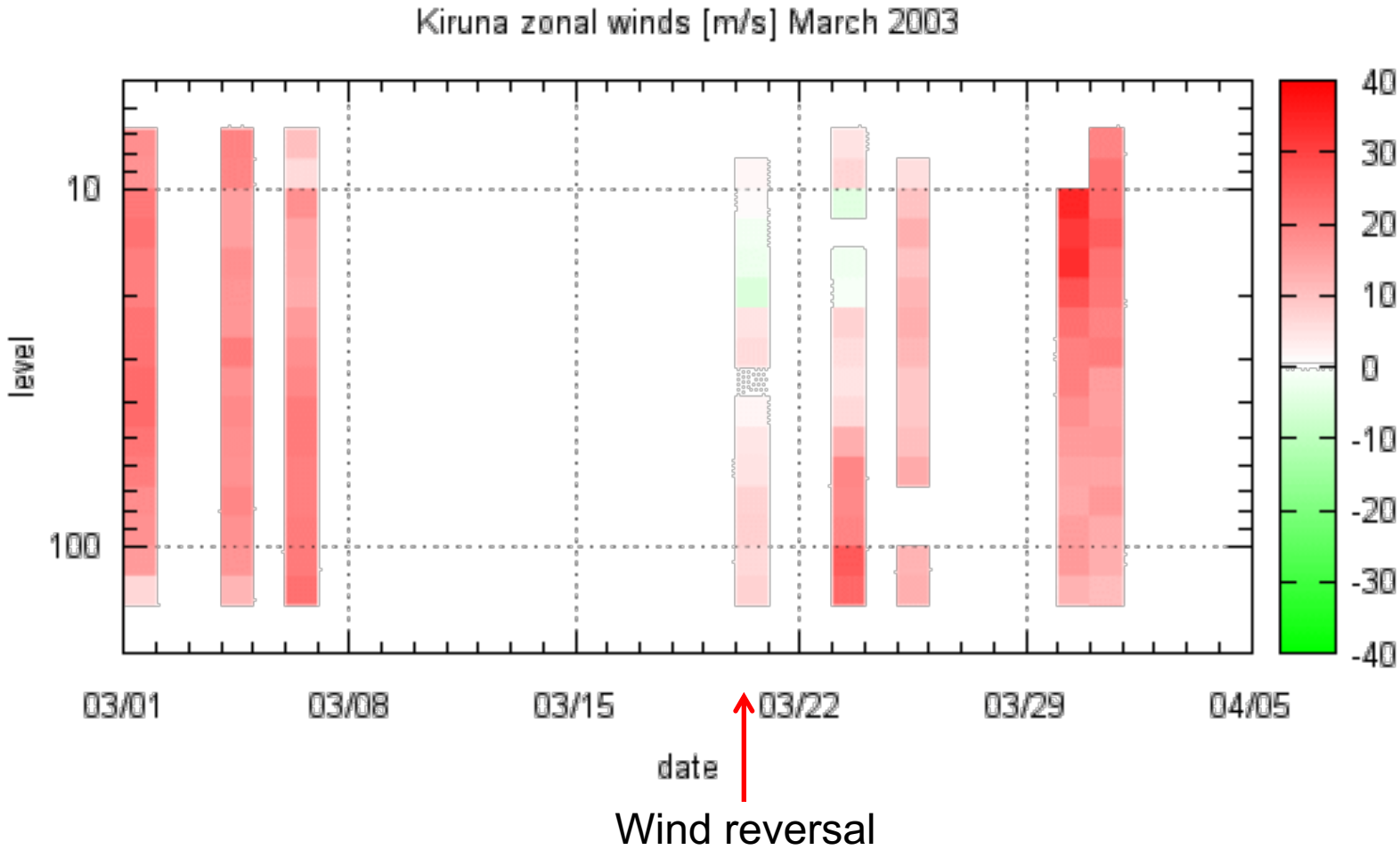
Kiruna soundings March 2003



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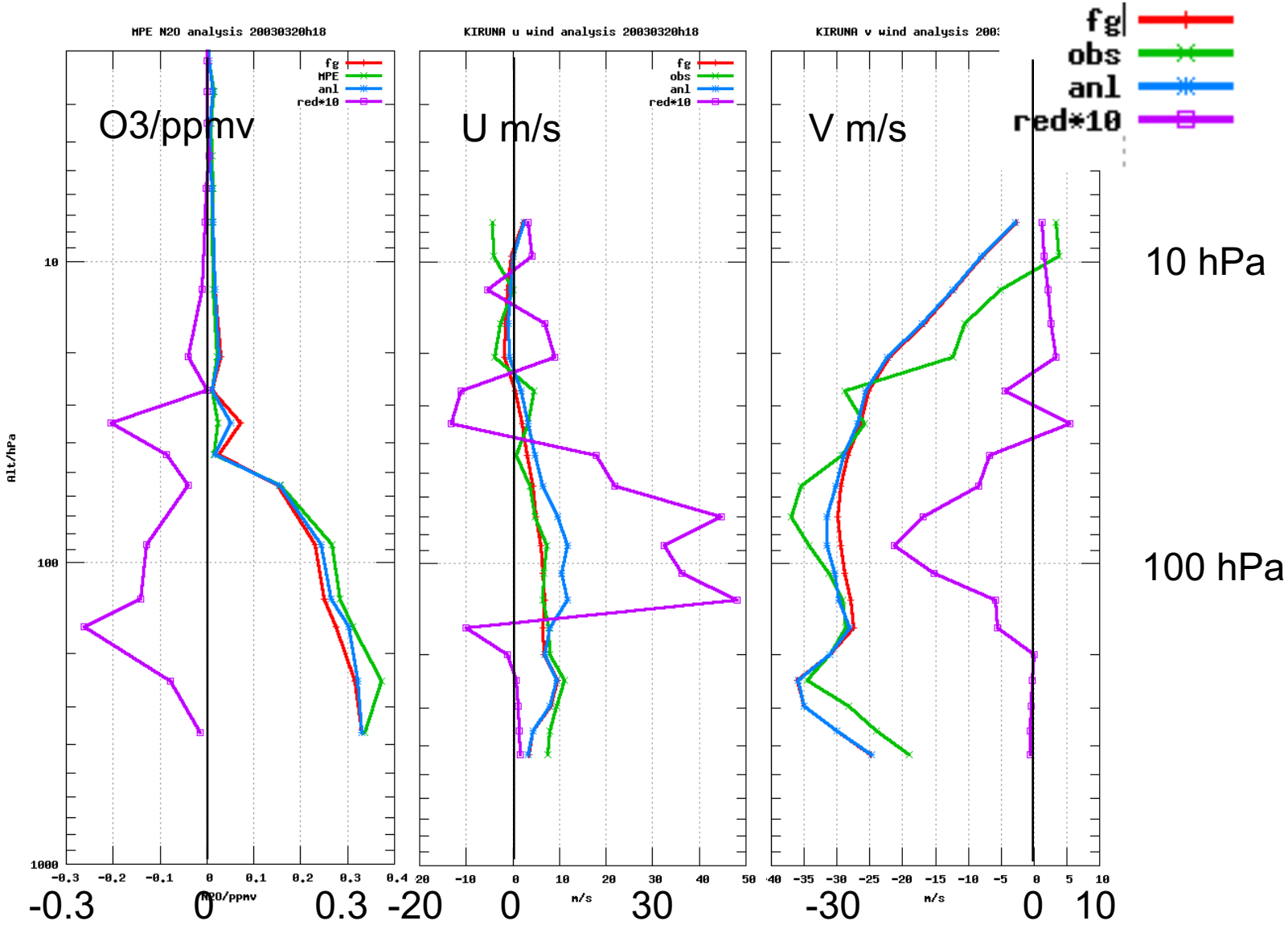
Wind & N2O tracer results for March 20, 2003



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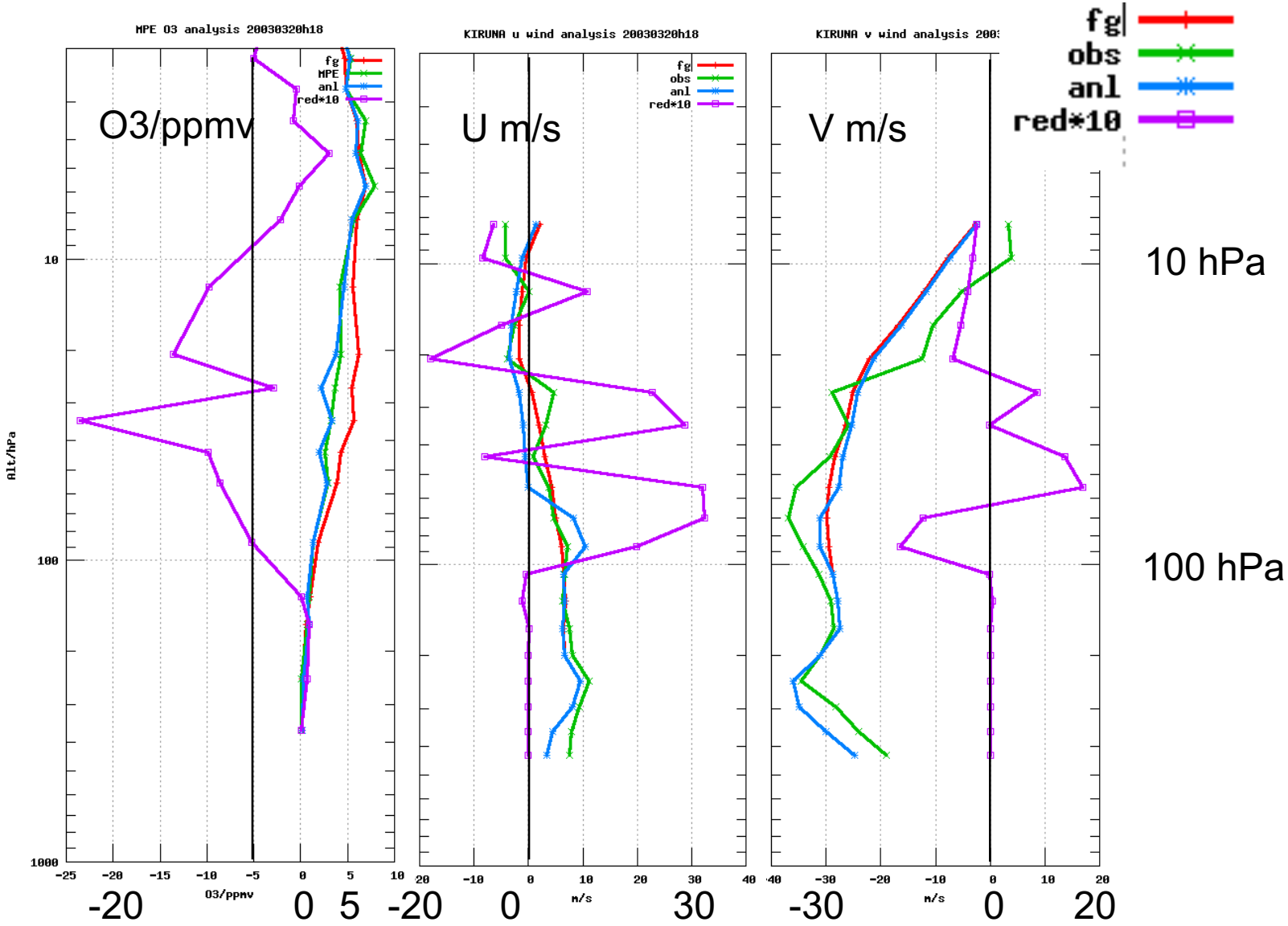
Wind & O3 tracer results for March 20, 2003



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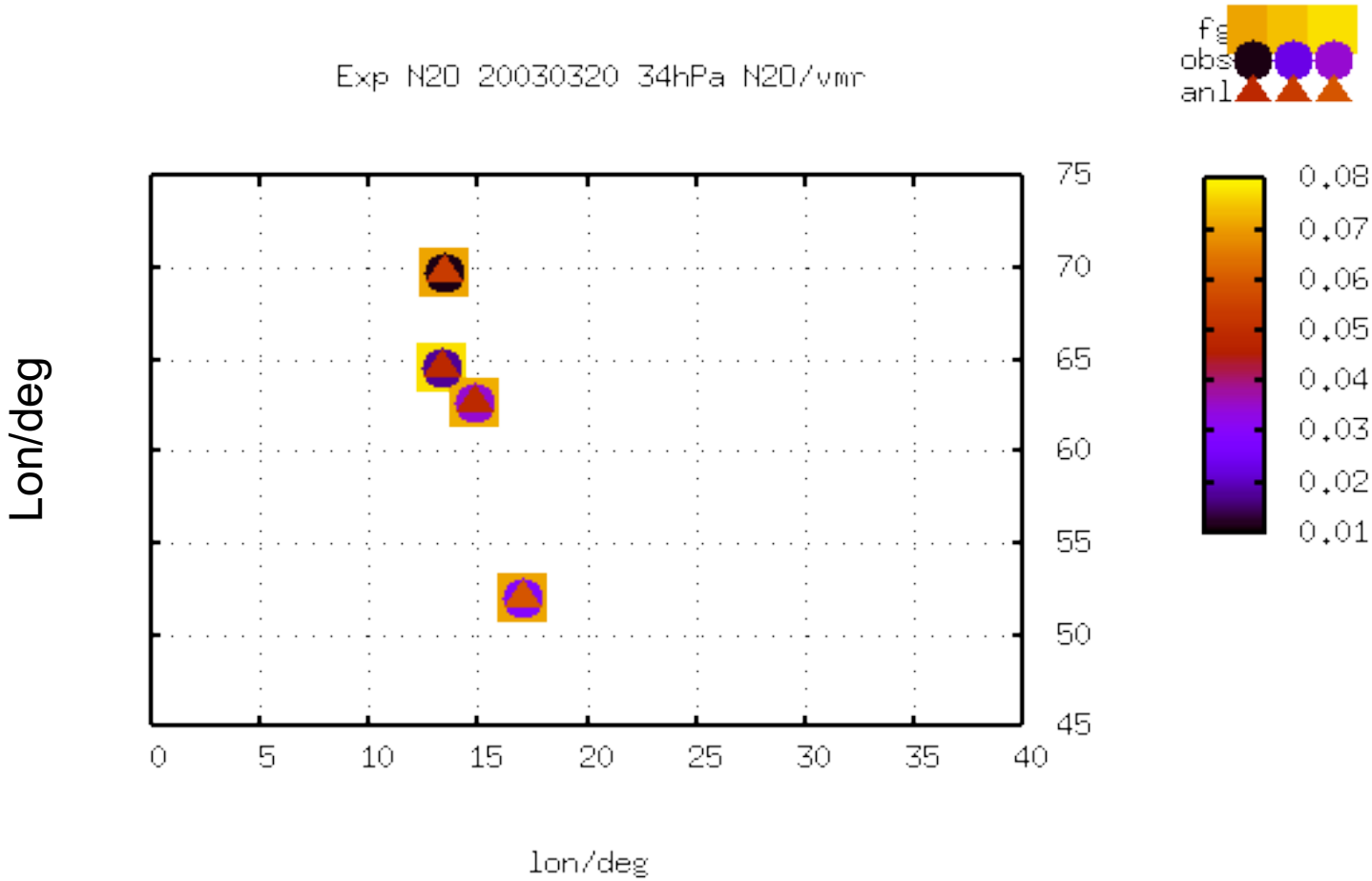
Effect of inversion on wind and tracer fields



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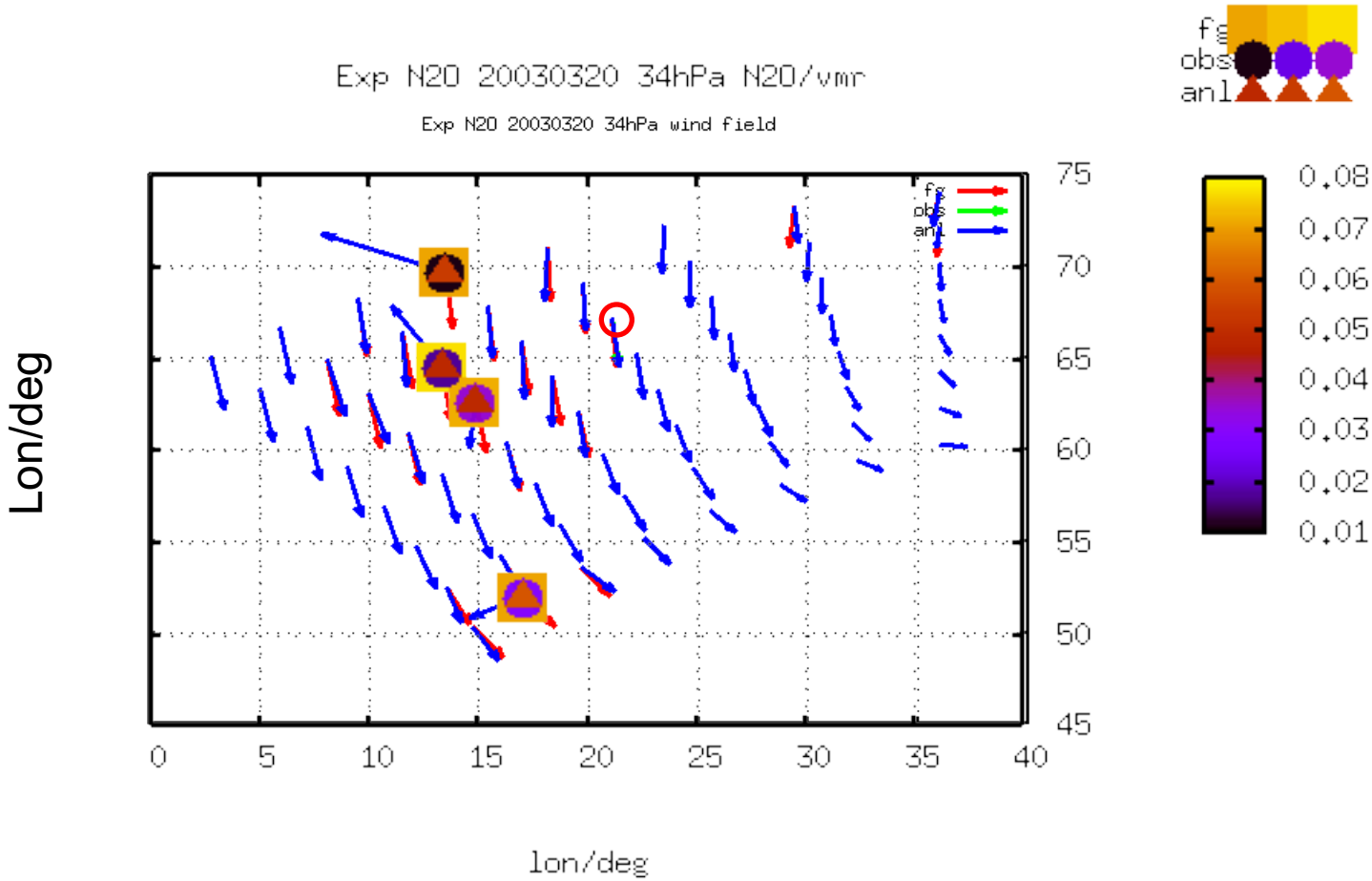

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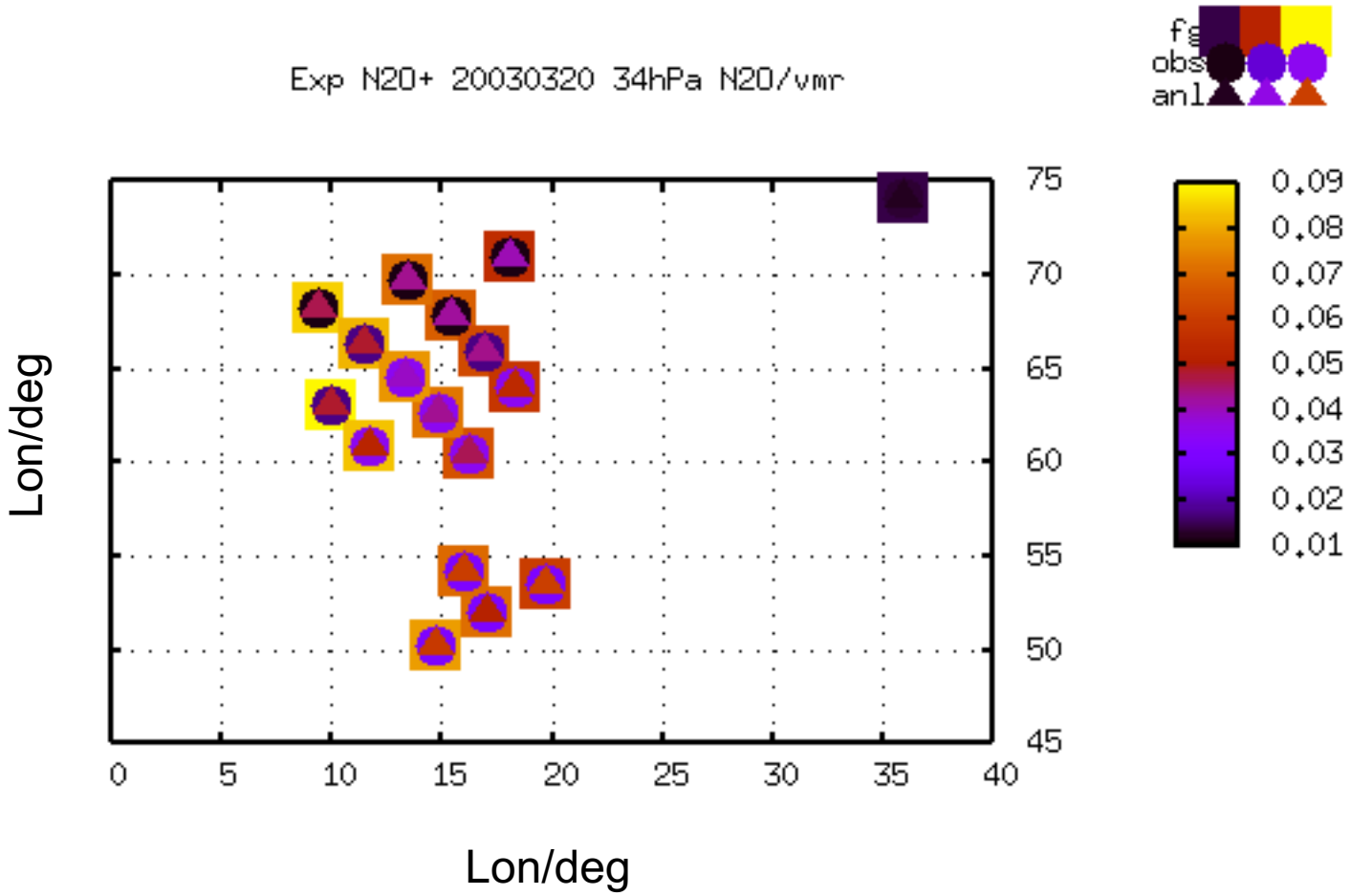
MIPAS with extended influence radius



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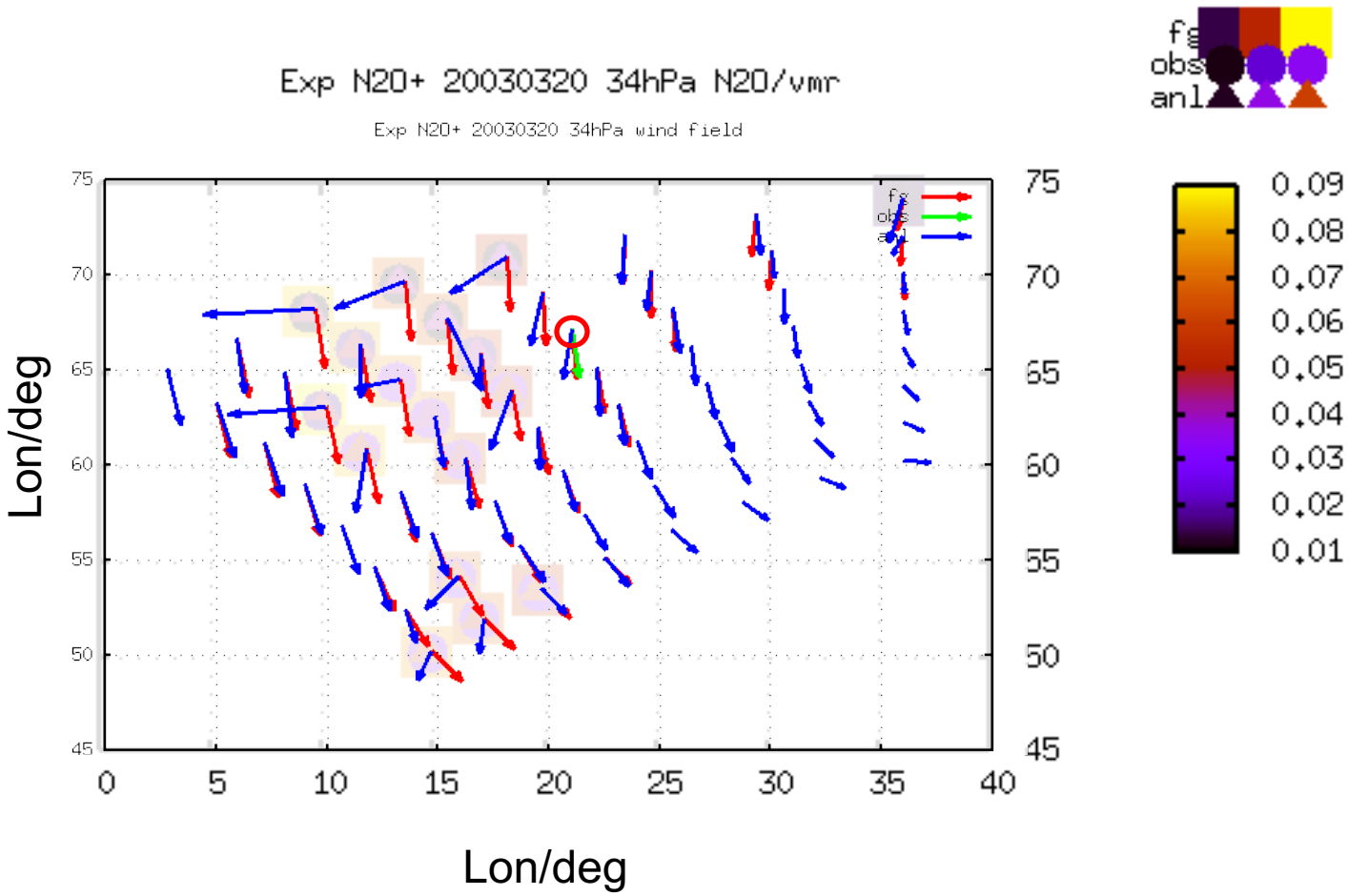
Effect of inversion on wind and tracer fields



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Discussion

- Improving wind fields is a challenge:
  - First-guess winds were already close to observations
  - Rapid loss of skill compared to chemical tracers
- Caveats:
  - Missing background-error
  - Constant wind assumption
  - MIPAS 6h coverage

Summary

- Analyzed winds have positive effect on tracer fields
- Comparison to Kiruna shows:
  - More vertical variability (good)
  - Impact on winds strongly depends on H-operator/covariance

- To do:
  - Application to other soundings/latitudes
  - Add linear wind tendence term

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