Sensitivity to the RO observation operator when assimilating 35,000 radio occultations per day during ROMEX

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Background

Setup

- Using operational model cycle of the IFS (48R1)
- Run data assimilation experiments for Sept – Nov 2022

Verification against operational analysis and observations

- Fits to independent observations
- Forecast scores (Std dev., RMSE, Anomaly correlation)
- Omit first 9 days in verification statistics to avoid including spinup issues

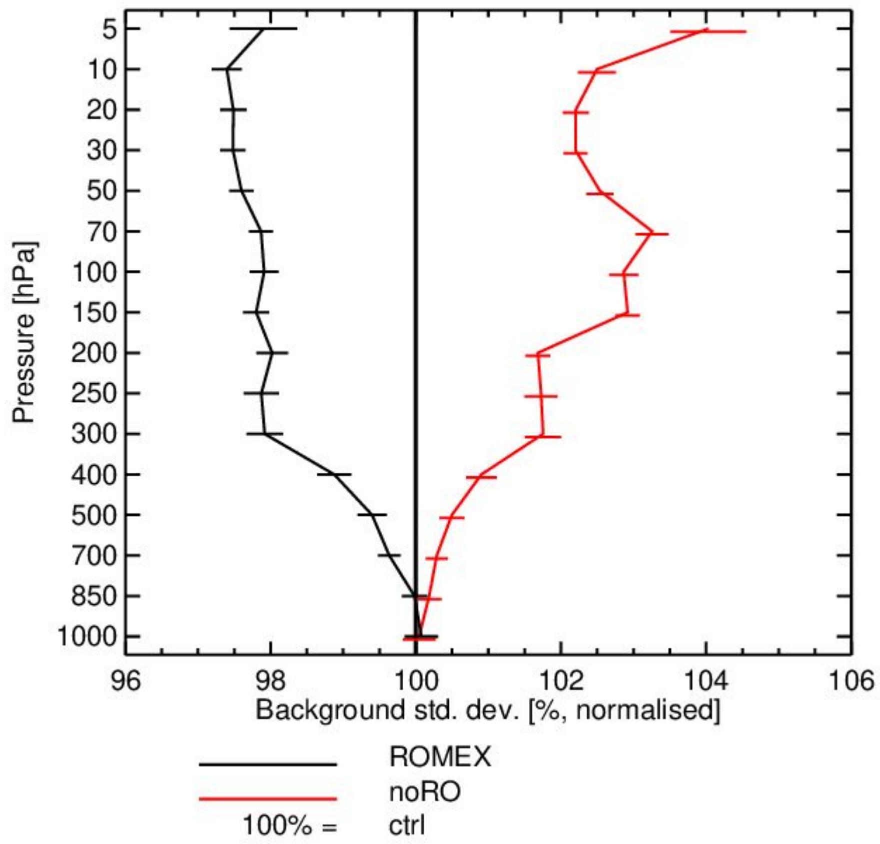
Experiments

id	description
ctrl	Baseline (all GNSS-RO data excl. commercial and Chinese data)
ROMEX	All ROMEX data
noRO	No GNSS-RO data

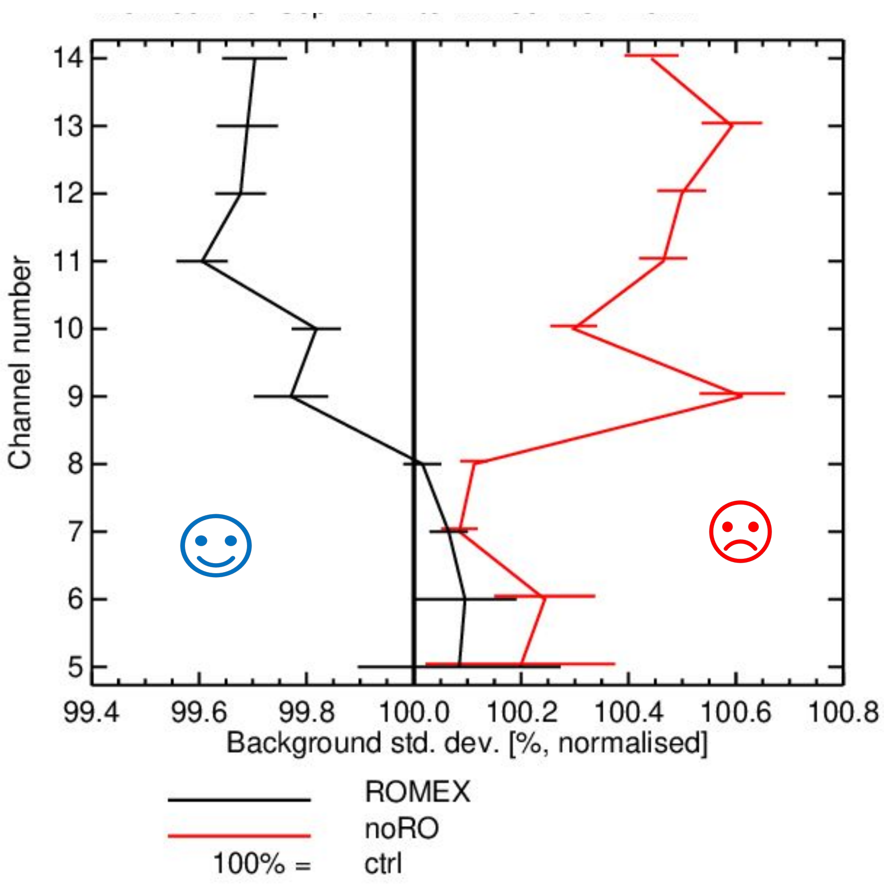
Impact on short-range forecasts (12h):

Change in std dev in First Guess departures (globally)

Radiosonde temperature



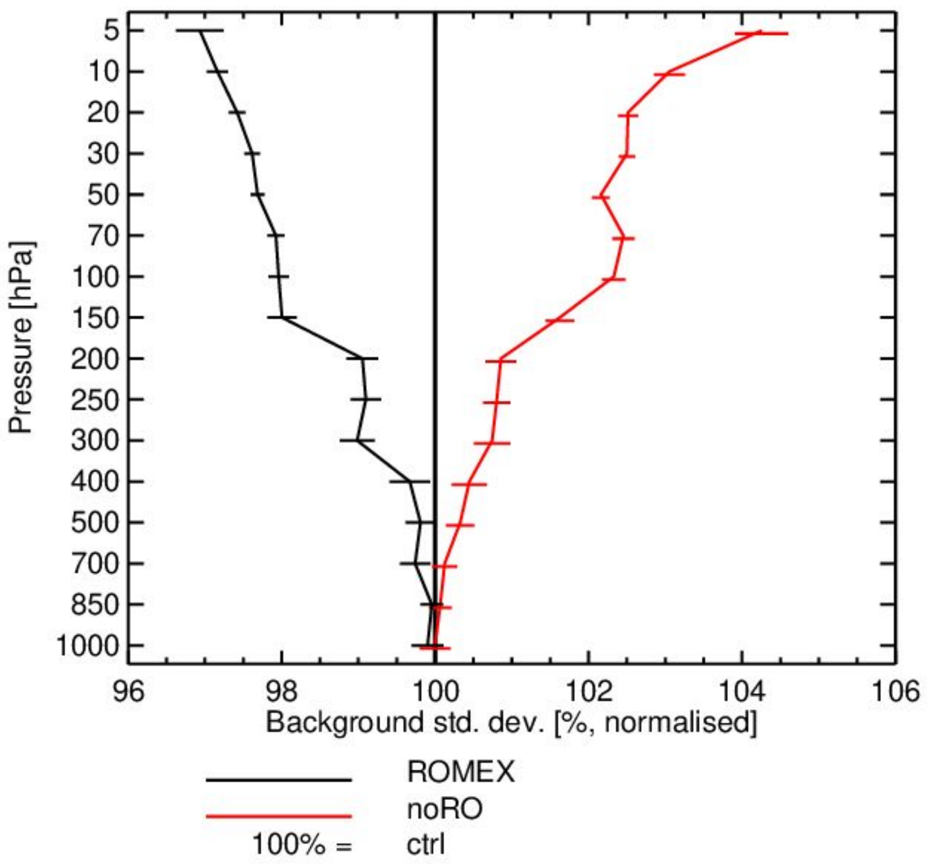
AMSU-A



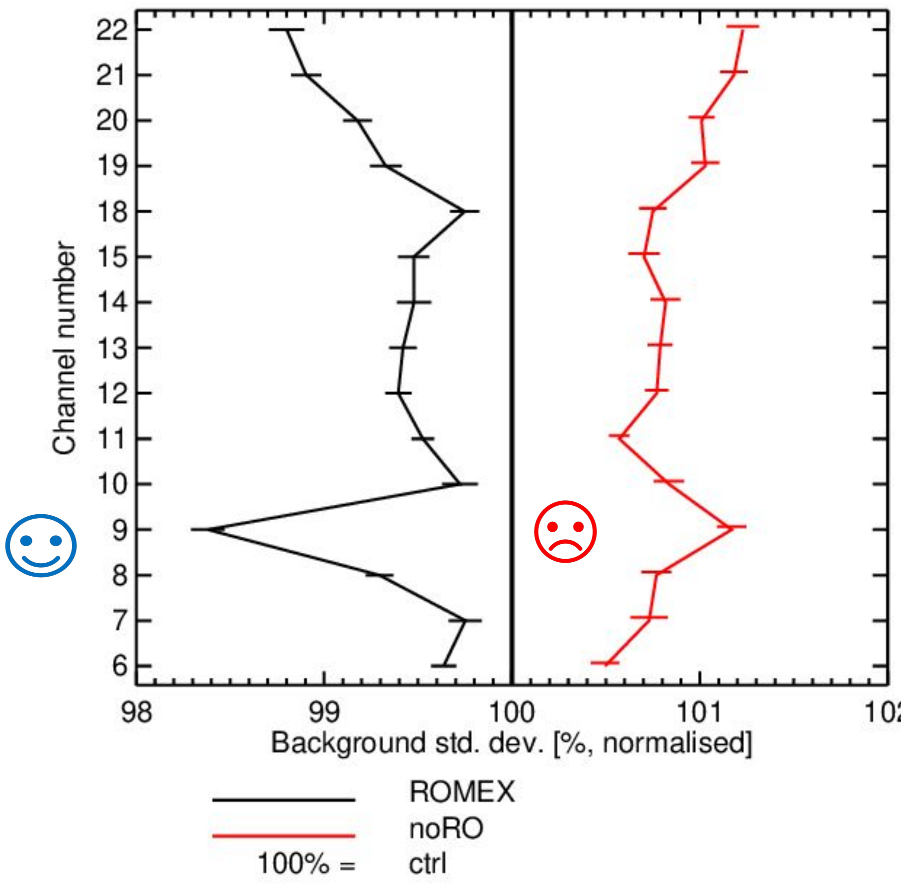
Impact on short-range forecasts (12h):

Change in std dev in First Guess departures (globally)

Wind observations

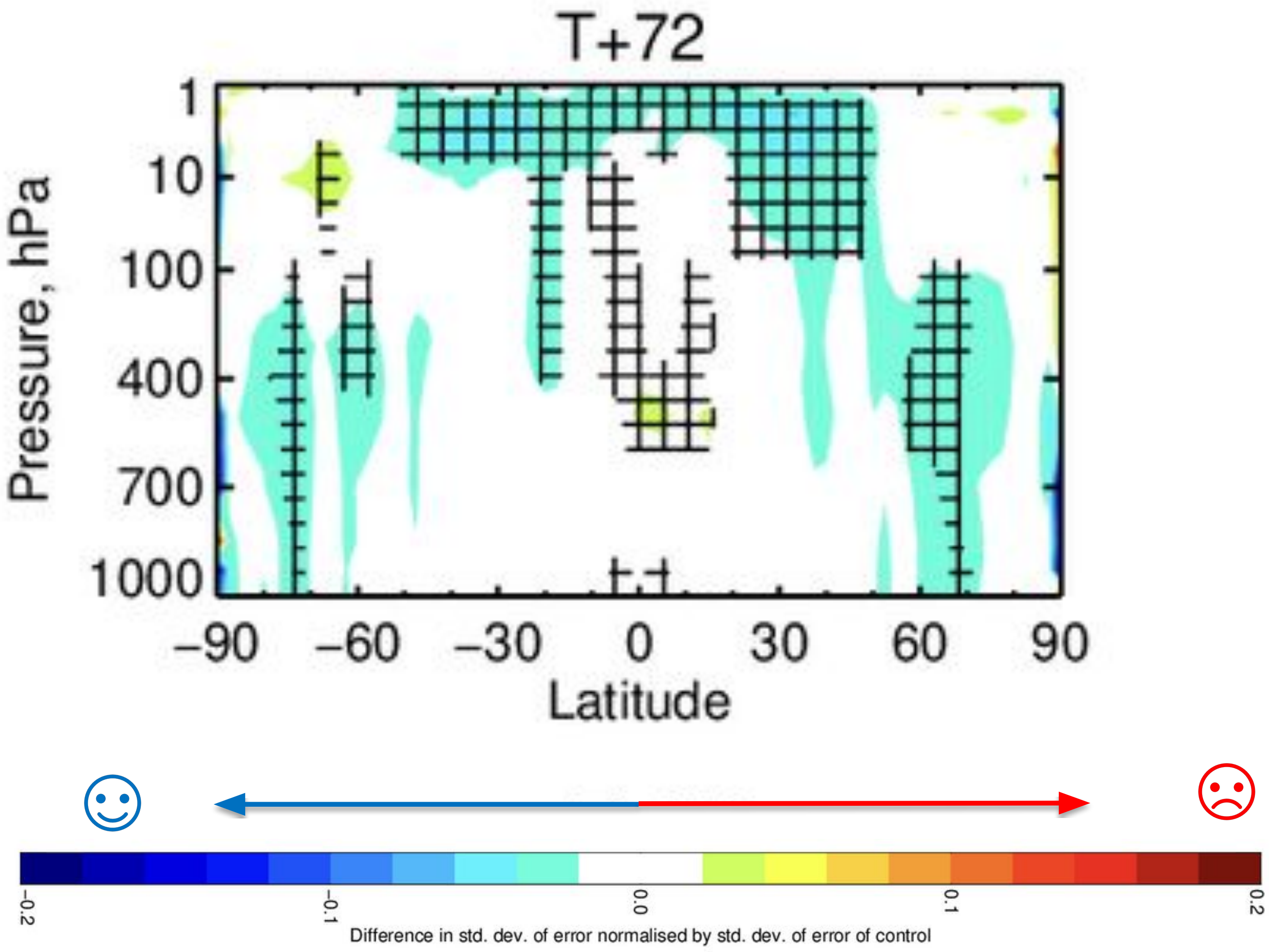


ATMS



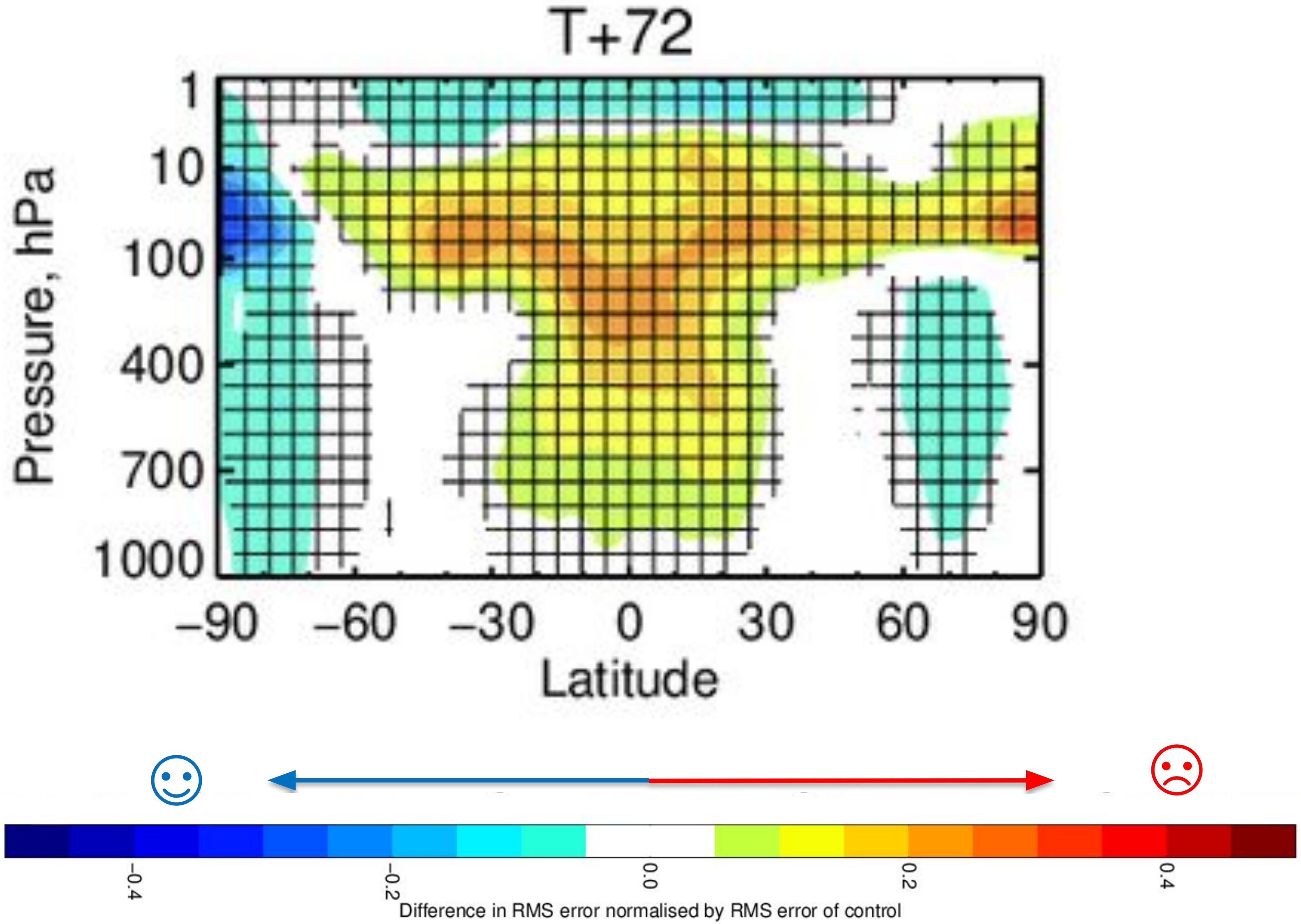
Decrease in Std dev for Geopotential forecast error

ROMEX - control

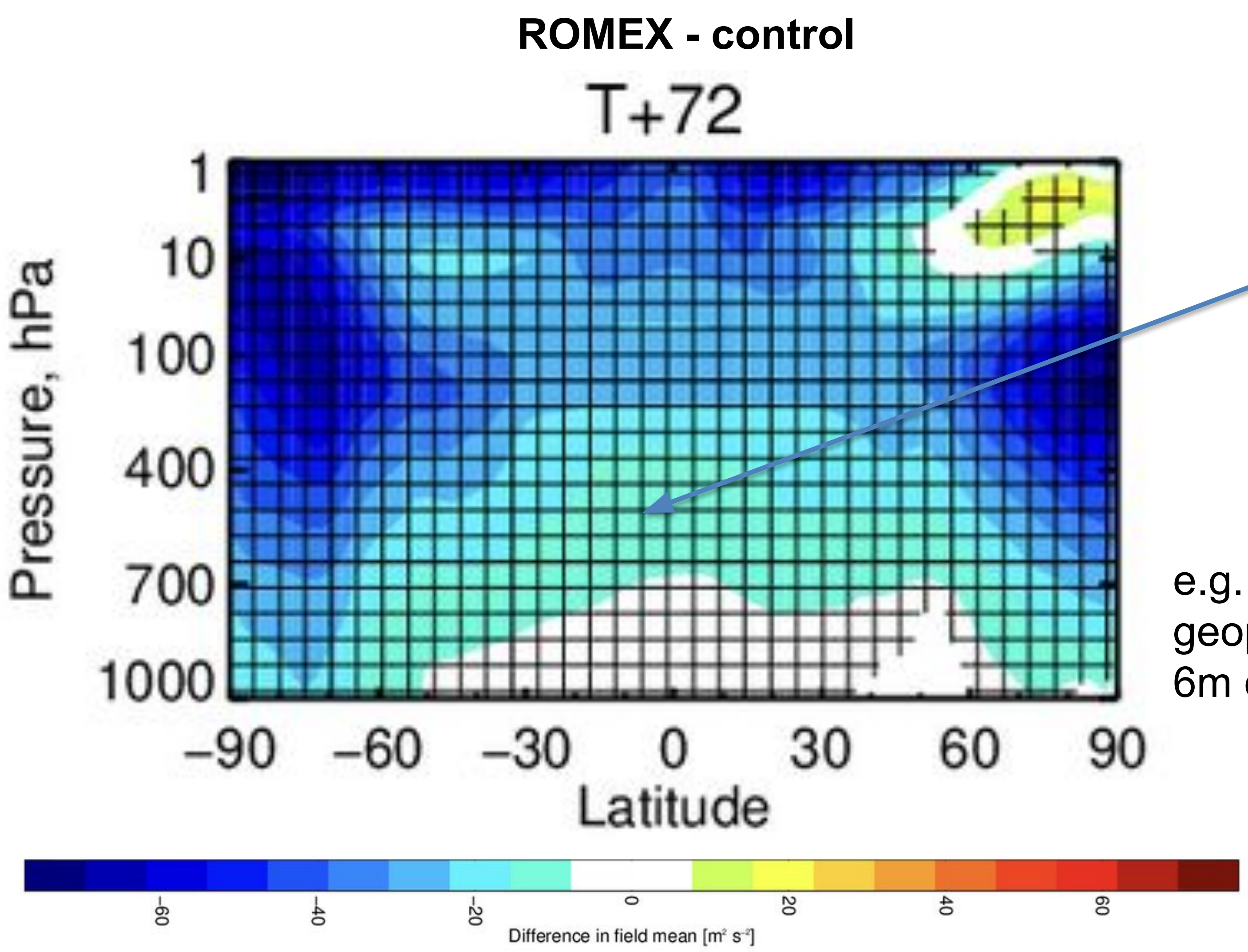


Increase in RMSE for Geopotential

ROMEX - control



Mean change in geopotential

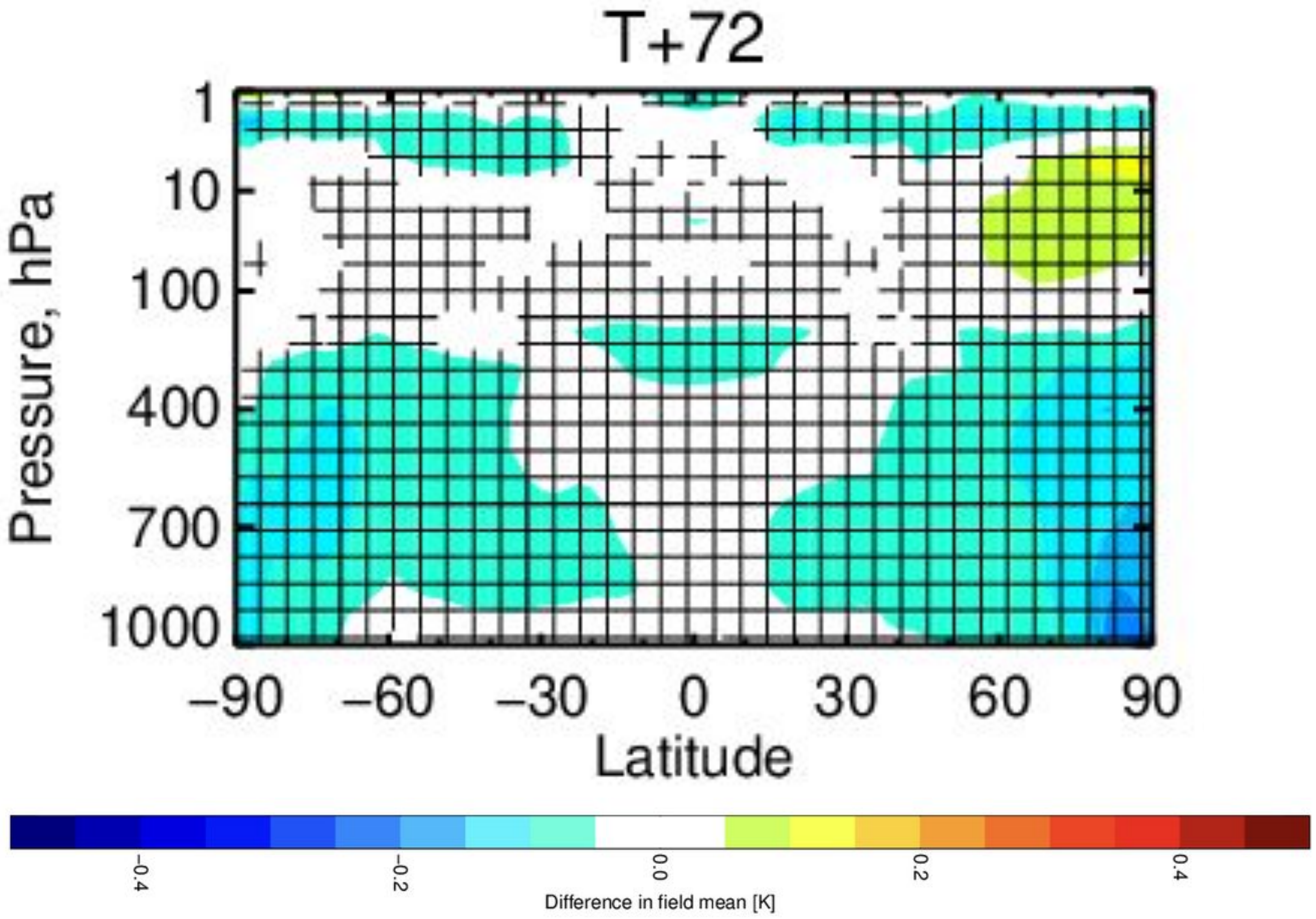


about 2-8 m change in geopotential height

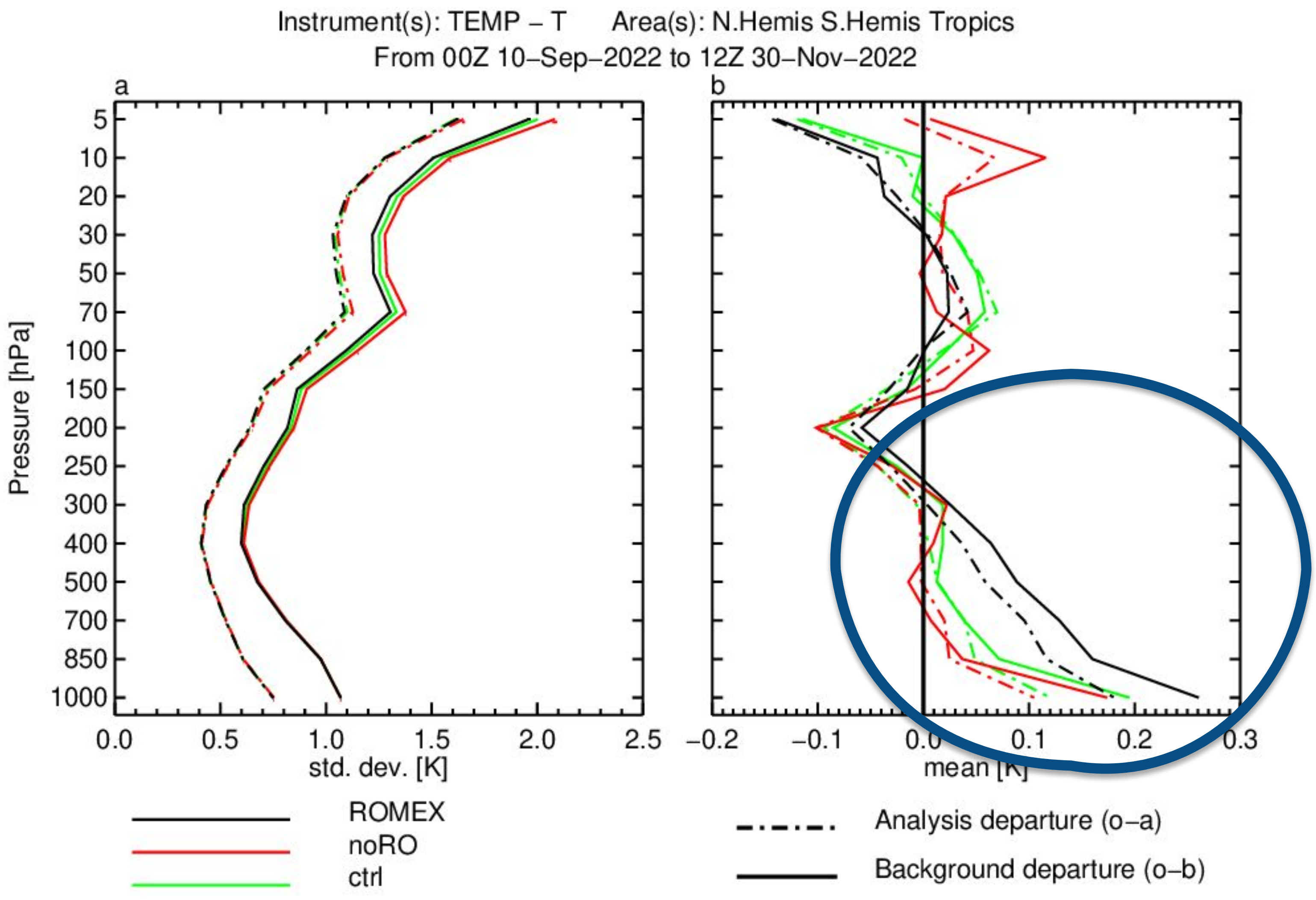
e.g. @ 500 hPa:
geopotential height ~ 5.75 km
6m change in $z_g \triangleq 0.1\%$

mean change in temperature

ROMEX - control



FGdep for Radiosonde Temperature



with ROMEX we seem to cool the troposphere too much.

Background

Setup

- Using operational model cycle of the IFS (48R1)
- Run data assimilation experiments for Sept – Nov 2022

Verification against operational analysis and observations

- Fits to independent observations
- Forecast scores (Std dev., RMSE, Anomaly correlation)
- Omit first 9 days in verification statistics to avoid including spinup issues

Summary

- Good forecast scores (std dev) and fits to independent observations for wind, temperature and geopotenial
- **Slight increase in mean error for Geopotential height** (5 m), caused by cooler

Sensitivity Experiments

- small modifications of the GNSS-RO forward operator -

id	description
control	
ROMEX	
noRO	
ROMEX no 5km	Exclude GNSS-RO in lowest 5 km
ROMEX no hydro	Removing hydrostatic tail
- 7m	Take 7m off from geometric height
0.1% refrac coeff	Add 0.1% to refractivity coefficient N

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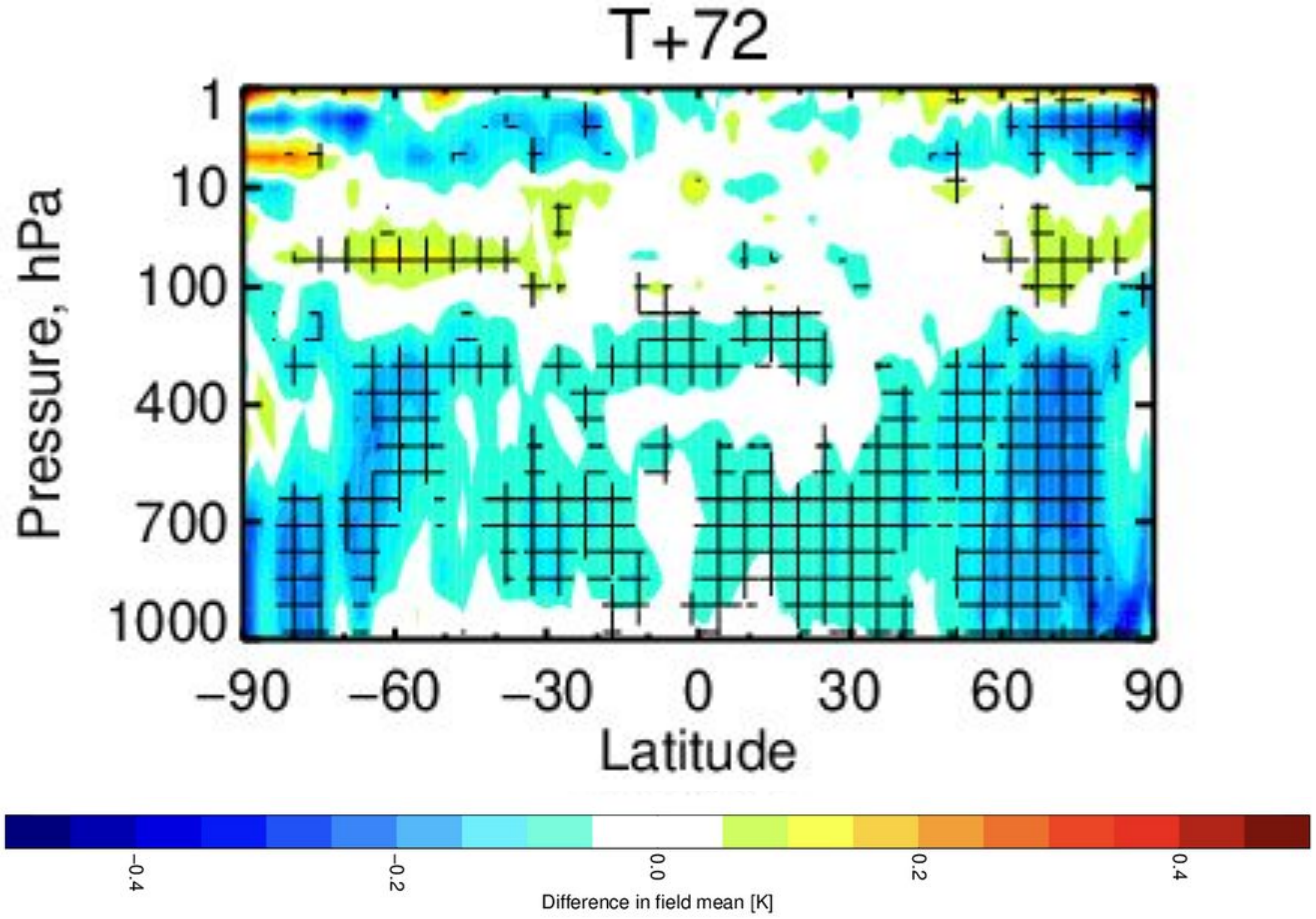
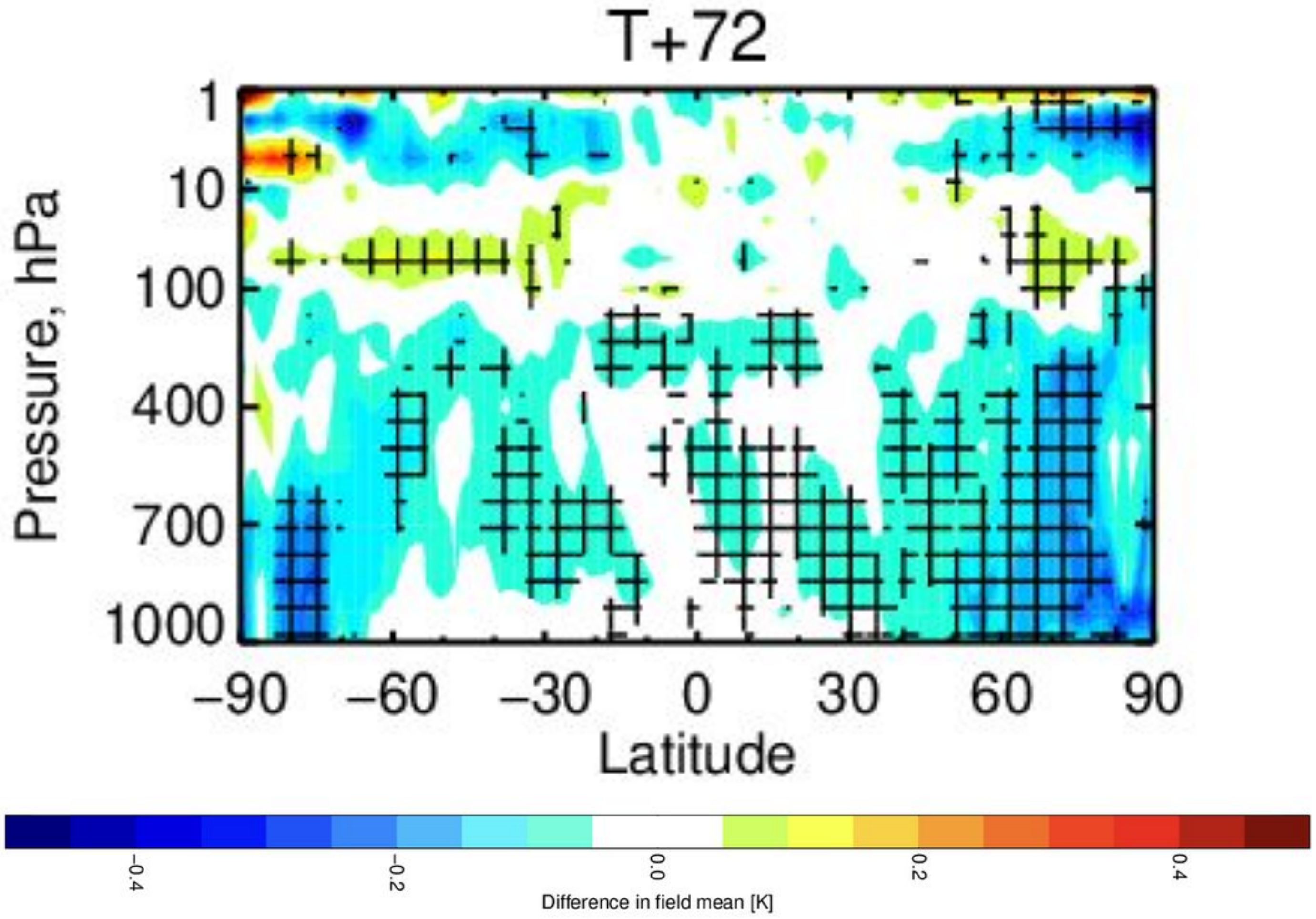
mean change in temperature

ROMEX - control

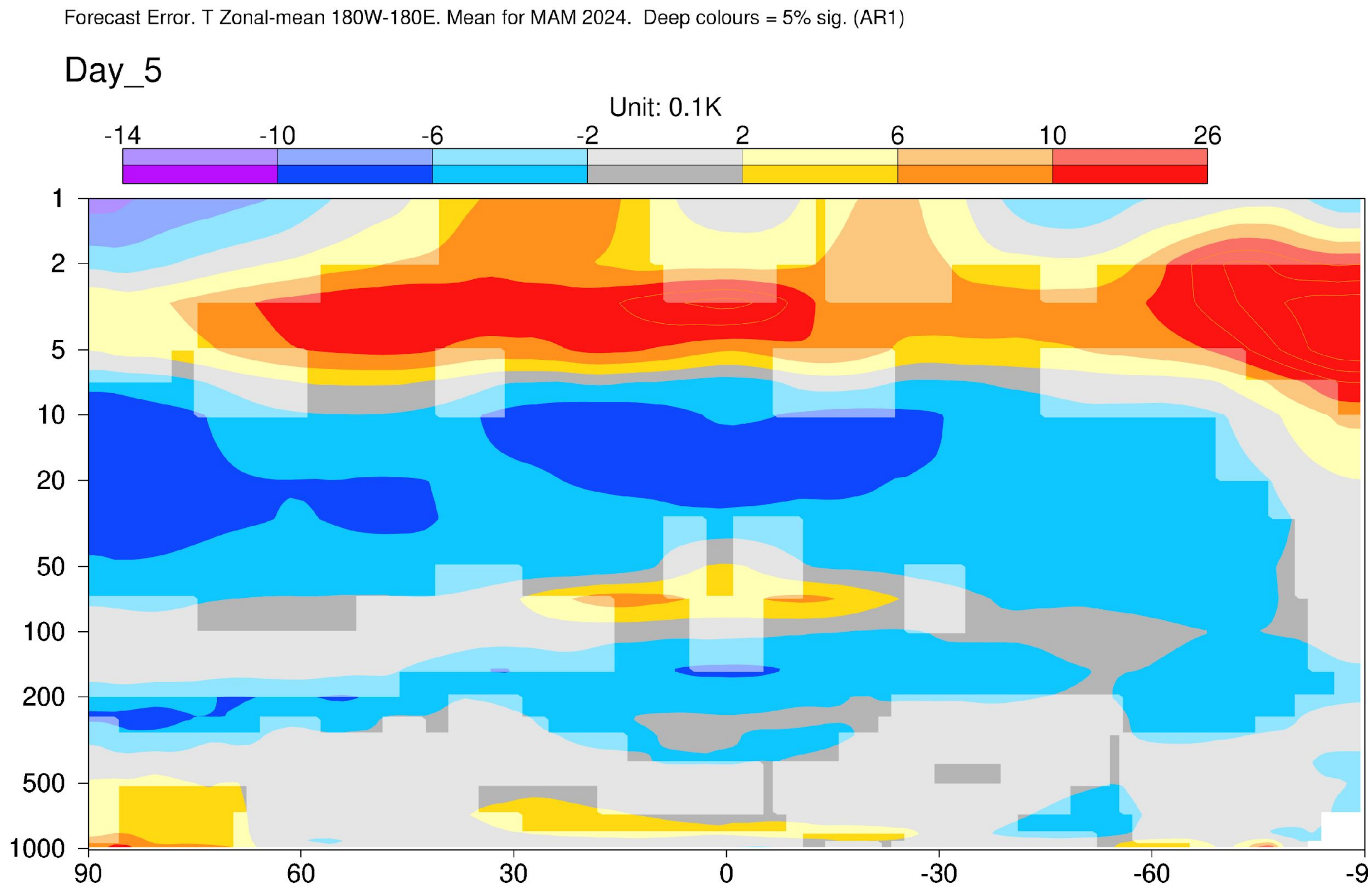


mean change in temperature

ROMEX no 5km - control



Biases in stratosphere



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Source: Summary by Healy for ECMWF Seminar on the Use of Satellite Observations in NWP, 8–12 September 2014

Hydrostatic tail

Large sensitivity to the temperature at the model level directly above and below the ray tangent height

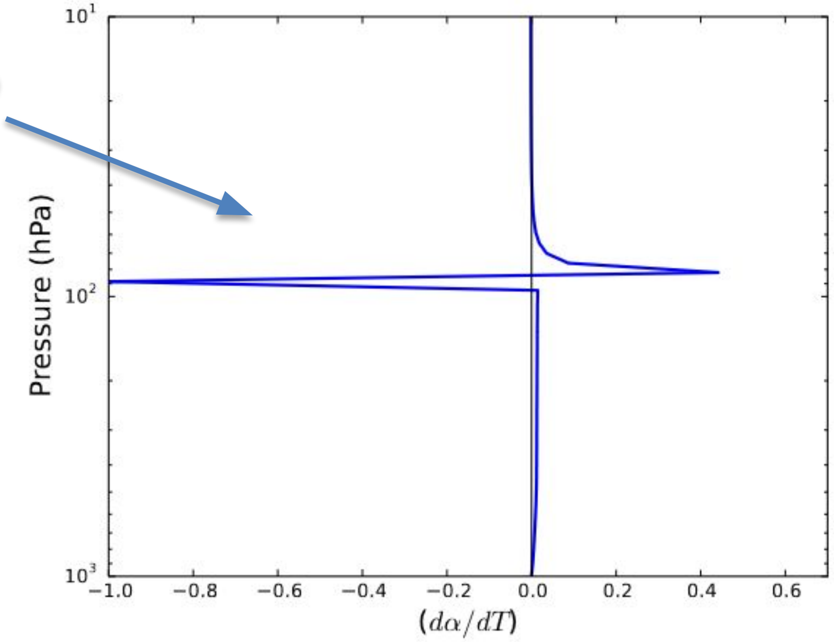

Figure 2: The temperature weighting function, $(\partial\alpha/\partial T)$, for stratospheric bending angle. The largest contributions are from the model levels directly above and below the observed tangent height. The long "hydrostatic" tail below the tangent point is caused by the sensitivity of the stratospheric model level heights to the tropospheric temperatures.

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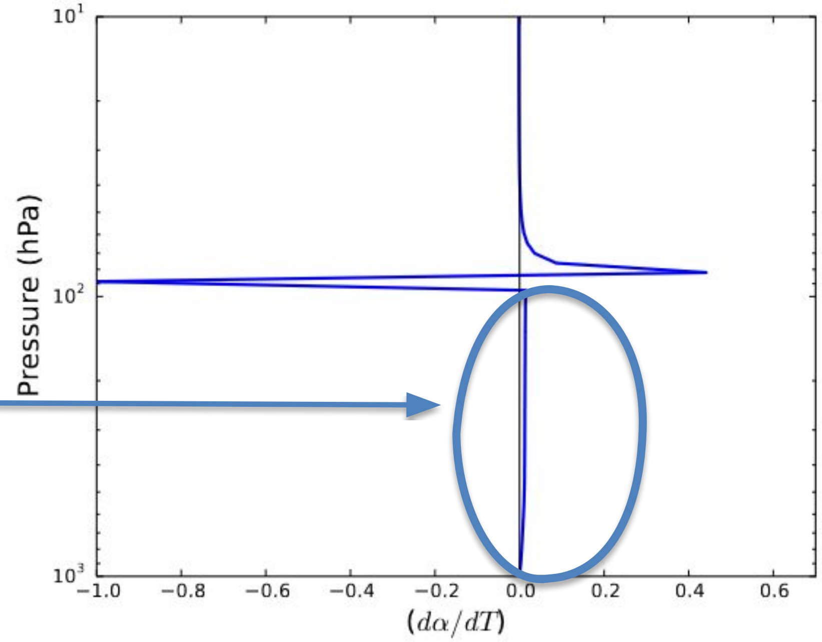
Below 100hPa in this case, there is a long positive "hydrostatic tail".



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Hydrostatic tail

Large sensitivity to the temperature at the model level directly above and below the ray tangent height

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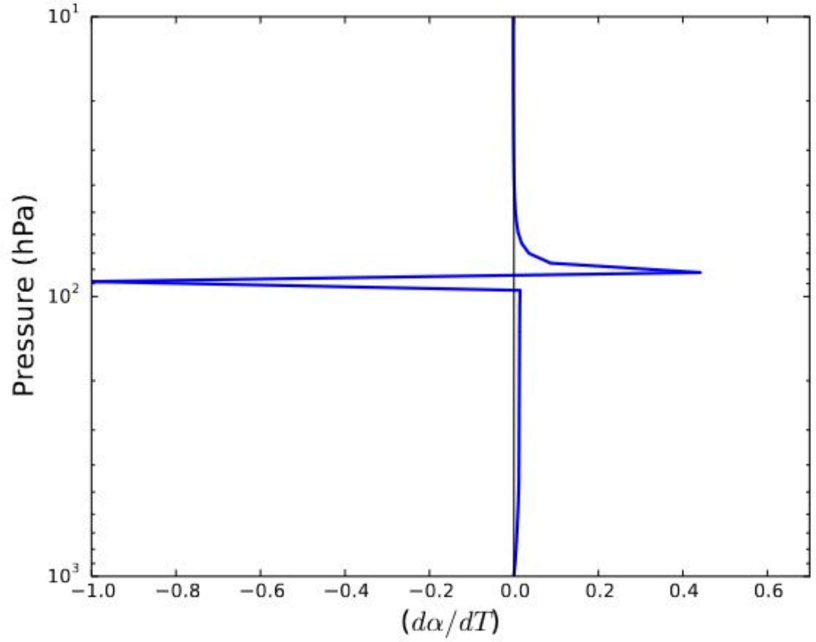
- sensitivity of the computed bending angles to the model level heights

→ GNSS-RO measurements provide surface pressure information (Healy, 2013).



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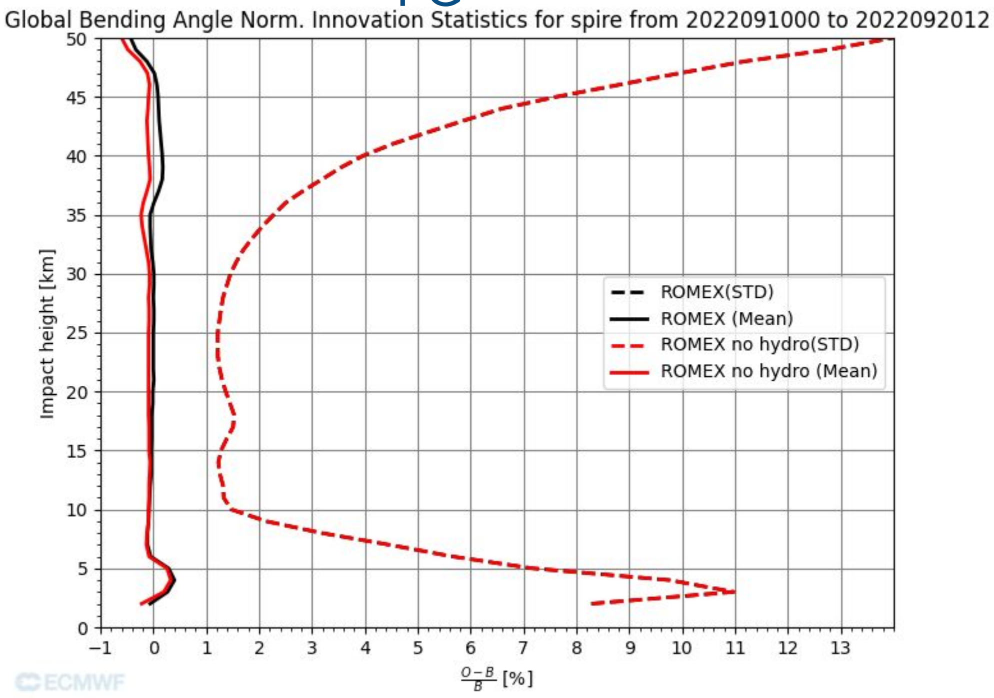
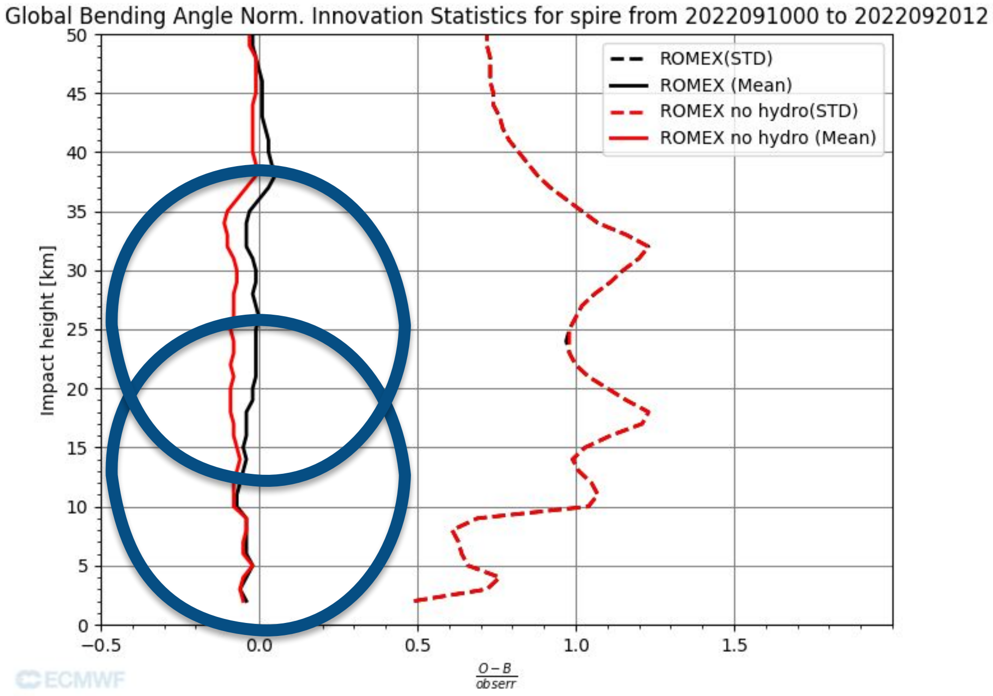
Normalised FG dep for Spire data

testing no hydrostatic tail

by FG

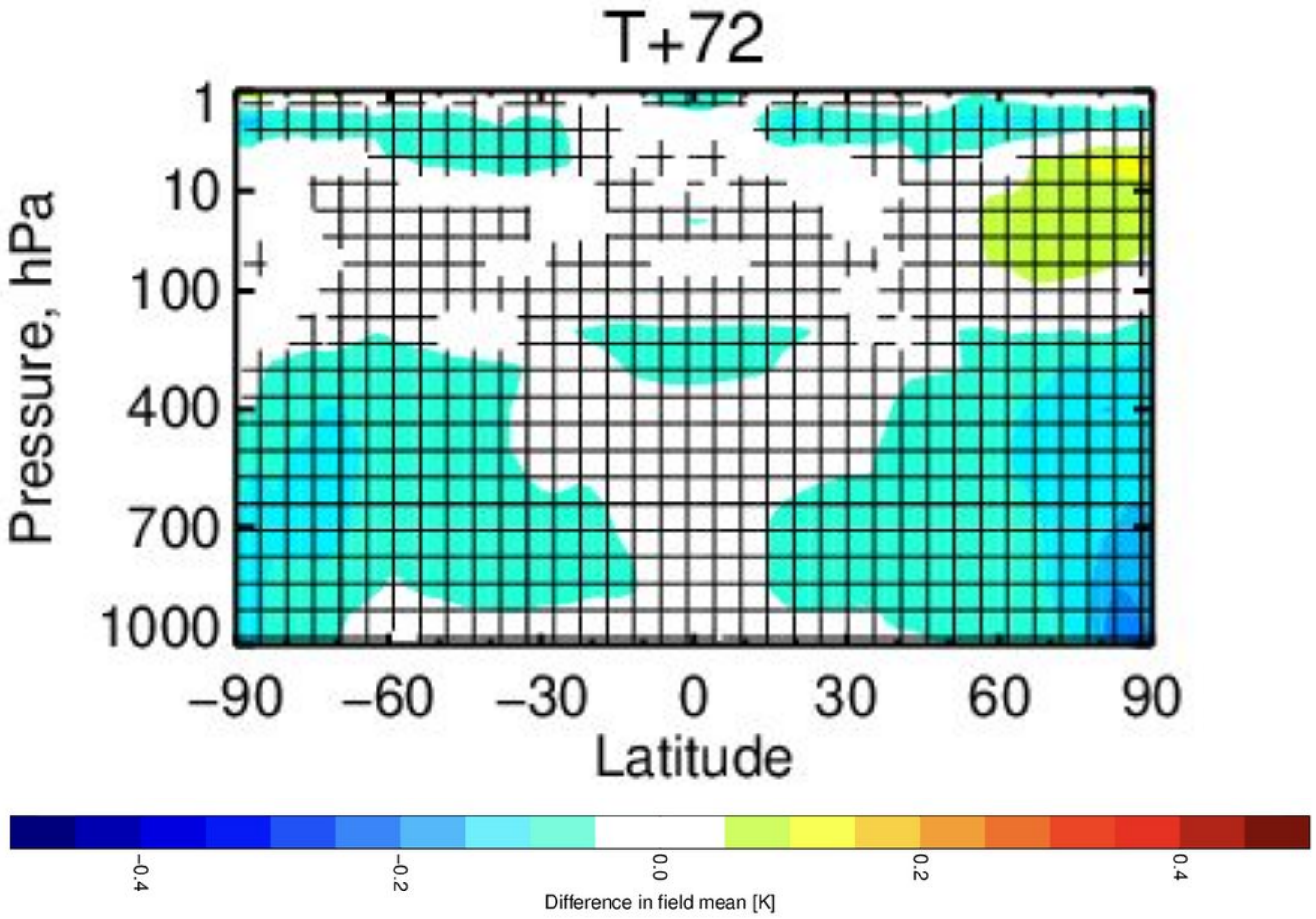


by obs error



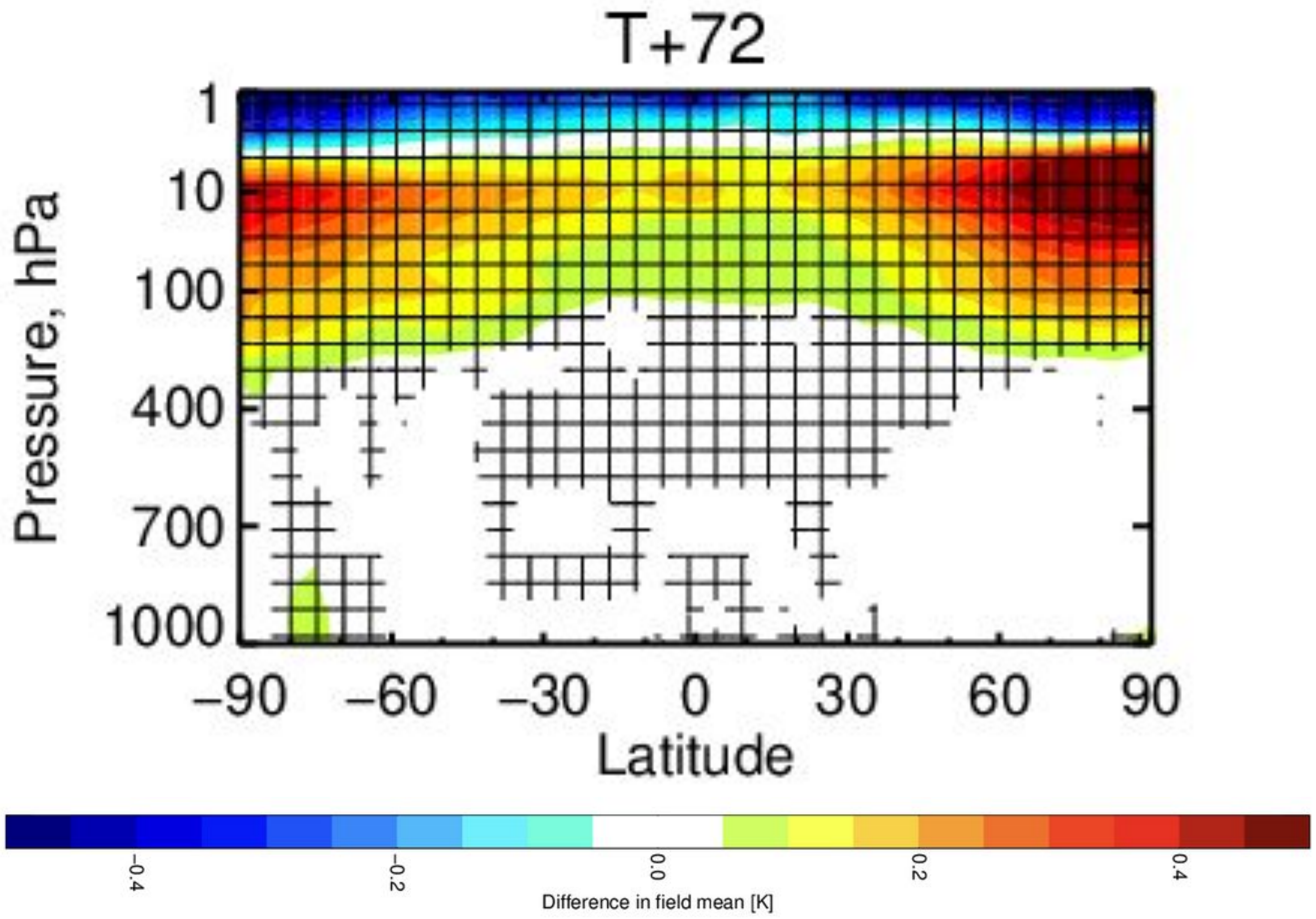
mean change in temperature

ROMEX - control



mean change in temperature

ROMEX no hydro - control



0.1% refrac coeff.

$N = k_1\, P_d/T + k_2\, e/T + k_3\, e/T^2$ incl. compressibility

Reduced the first refractivity coefficient by 0.1% in the 2D GNSS-RO forward operator to calculate dry part of refractivity calculation (incl. TL & ADJ)

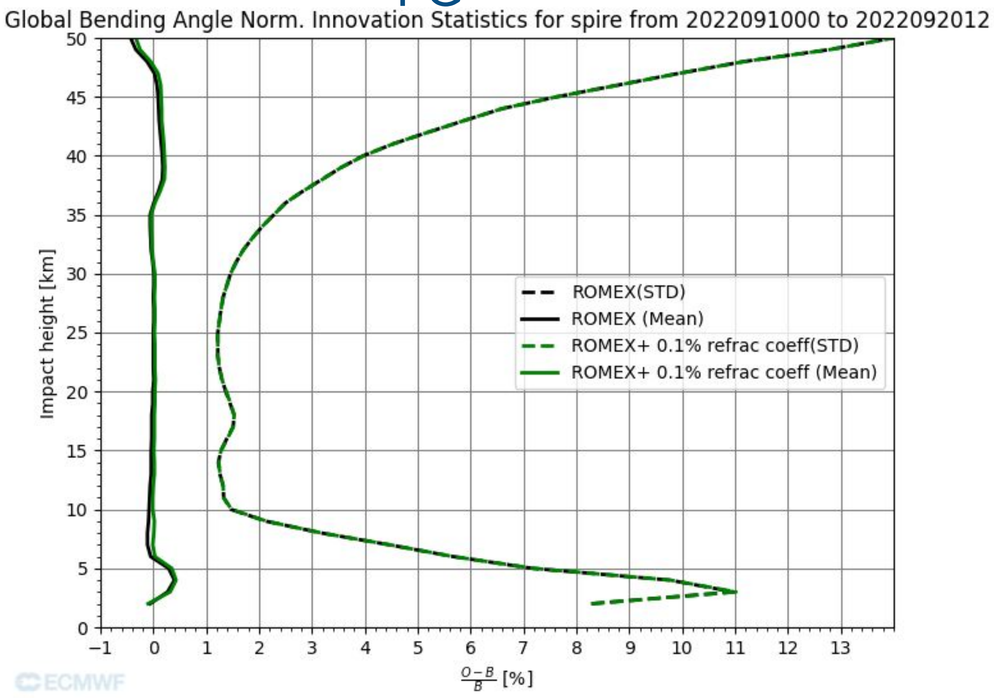
```
!!!REAL(KIND=JPRB), PARAMETER :: Z_AVAL = 0.77643_JPRB
REAL(KIND=JPRB), PARAMETER :: Z_AVAL = 0.77565_JPRB
```

```
Z_NDRY = Z_AVAL*Z_PD/P_TEMP(I,J)
```

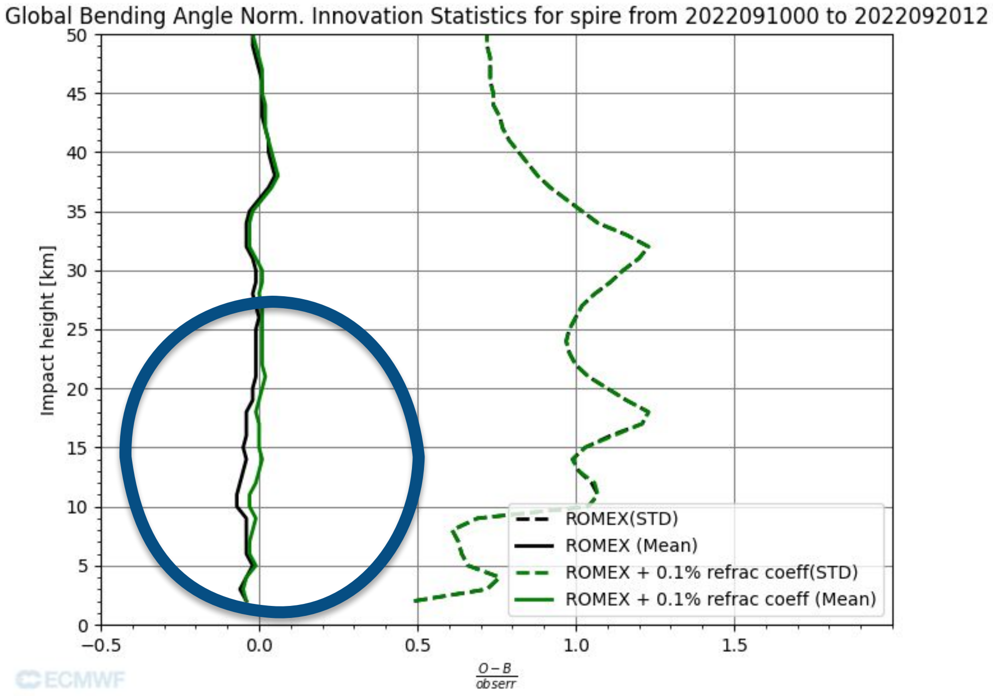
Normalised FG dep for Spire data

testing 0.1% refrac coeff

by FG

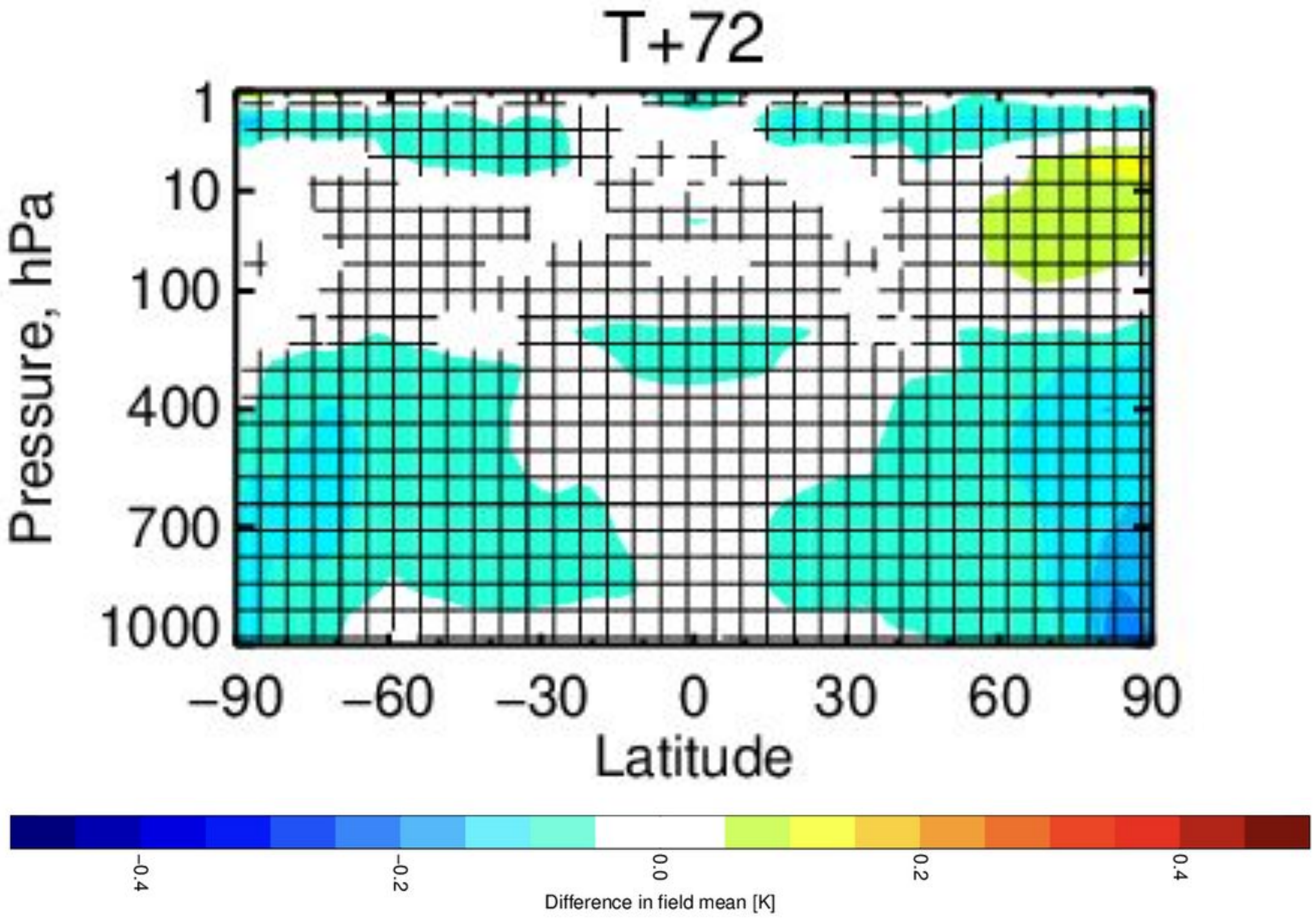


by obs error



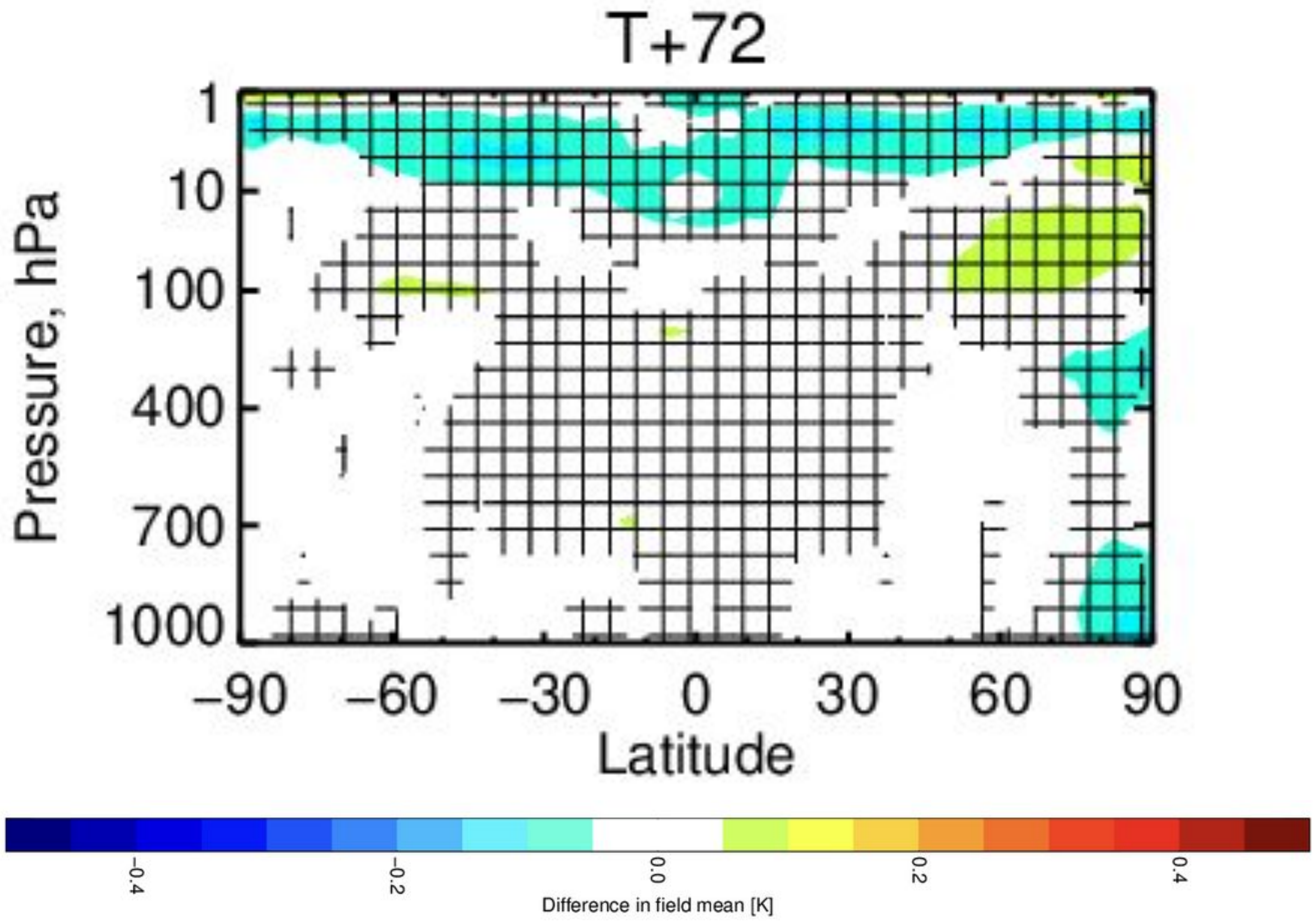
mean change in temperature

ROMEX - control



mean change in temperature

0.1% refrac coeff - control



- 7m

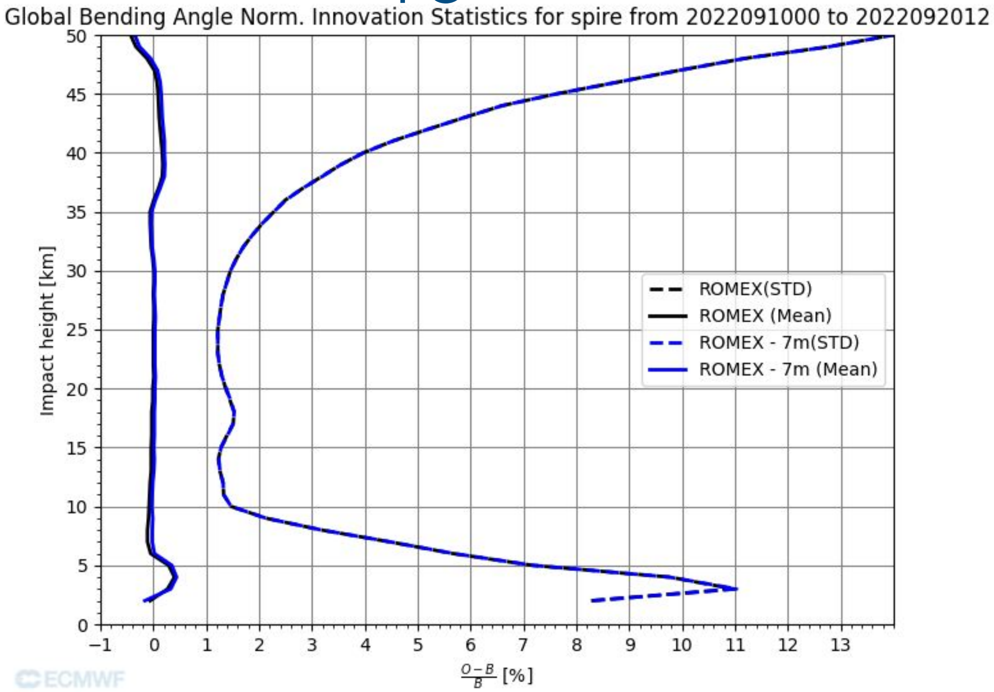
In the 2D forward operator for GNSS-RO, in the conversion from geopotential height to geometric height, we subtract 7m (gpscalc_nr2d.f90)

Height of 7m is ~0.1% scale height of refractivity, being ~7km

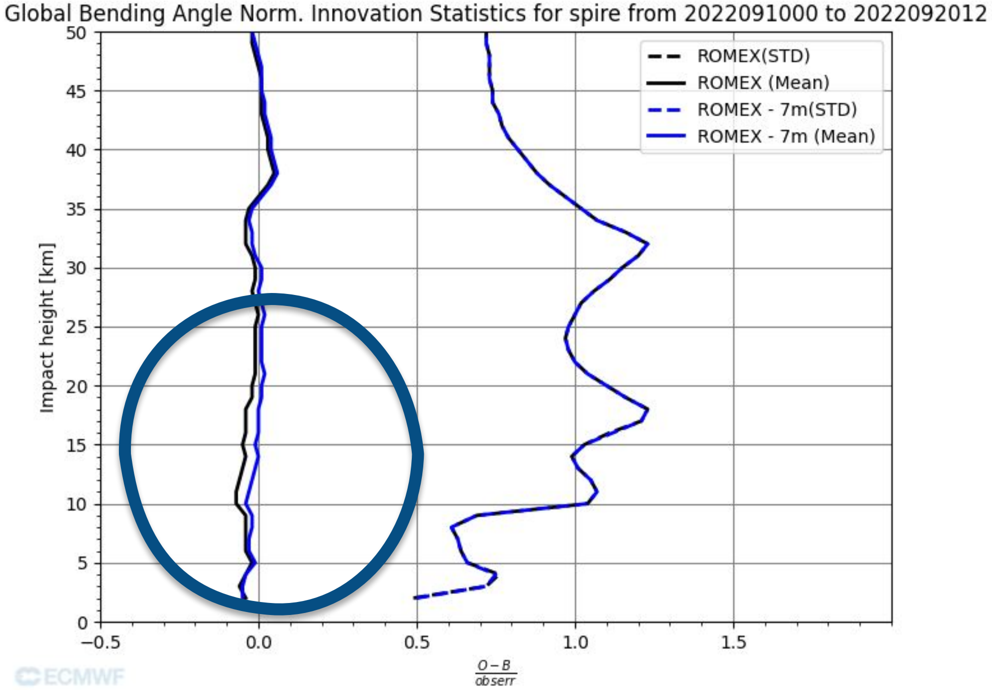
Normalised FG dep for Spire data

testing -7m

by FG

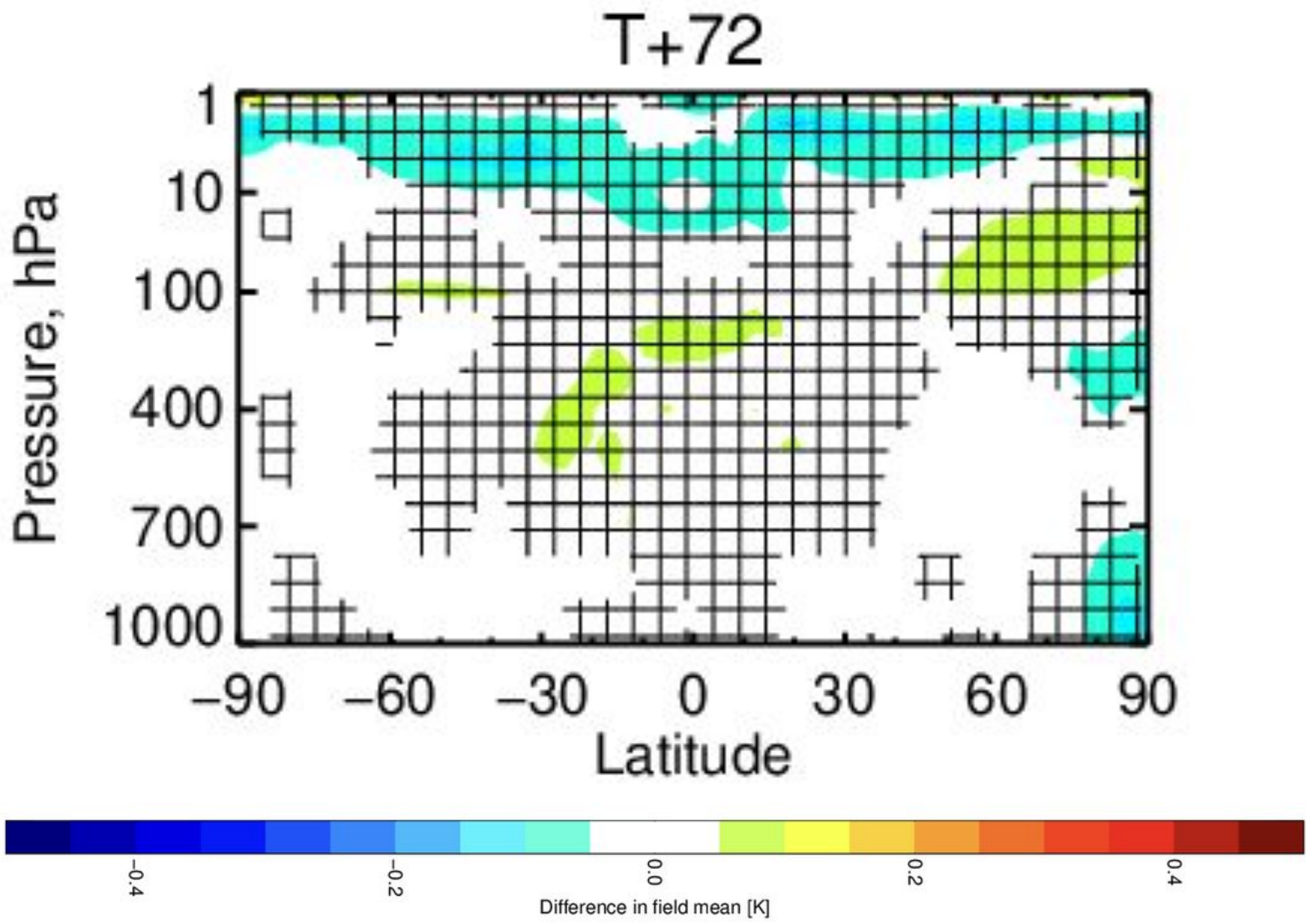


by obs error



mean change in temperature

- 7m - control

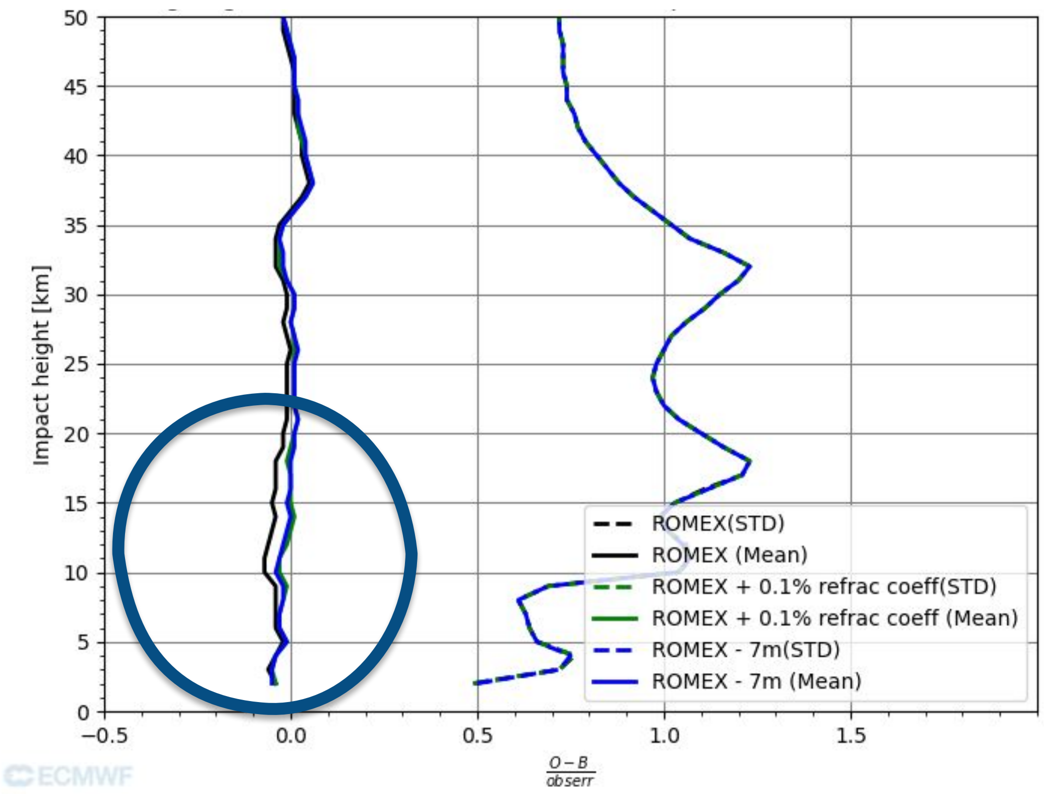


normalised FG dep for Spire data

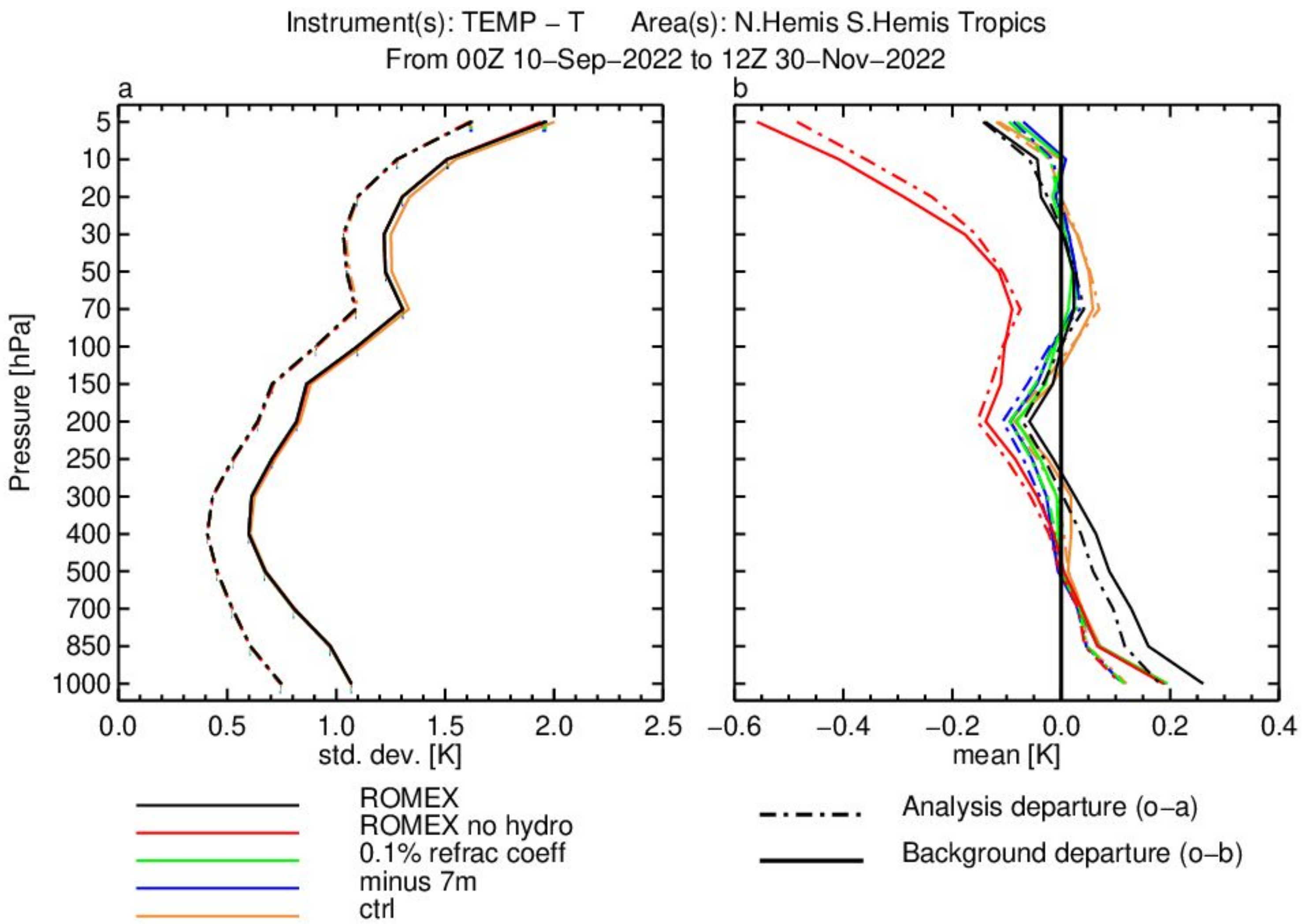
(by obs
error)

testing 0.1 % refrac coefficient in FO

testing substracting 7m in calculating geometric height in FO



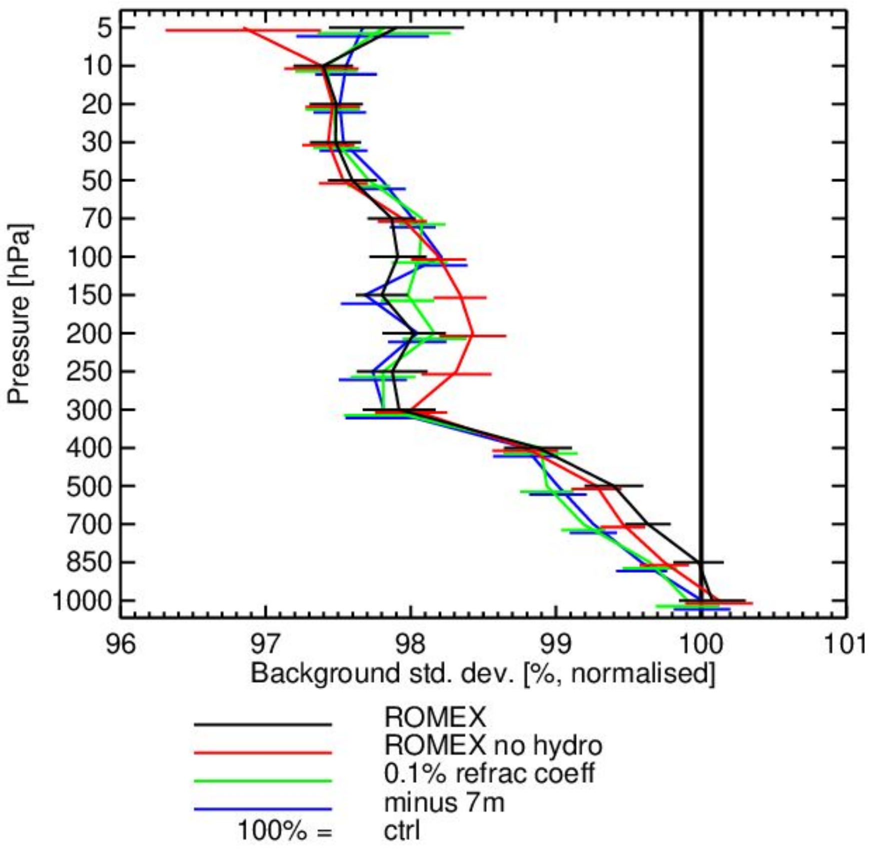
Fit to radiosonde temperature observations



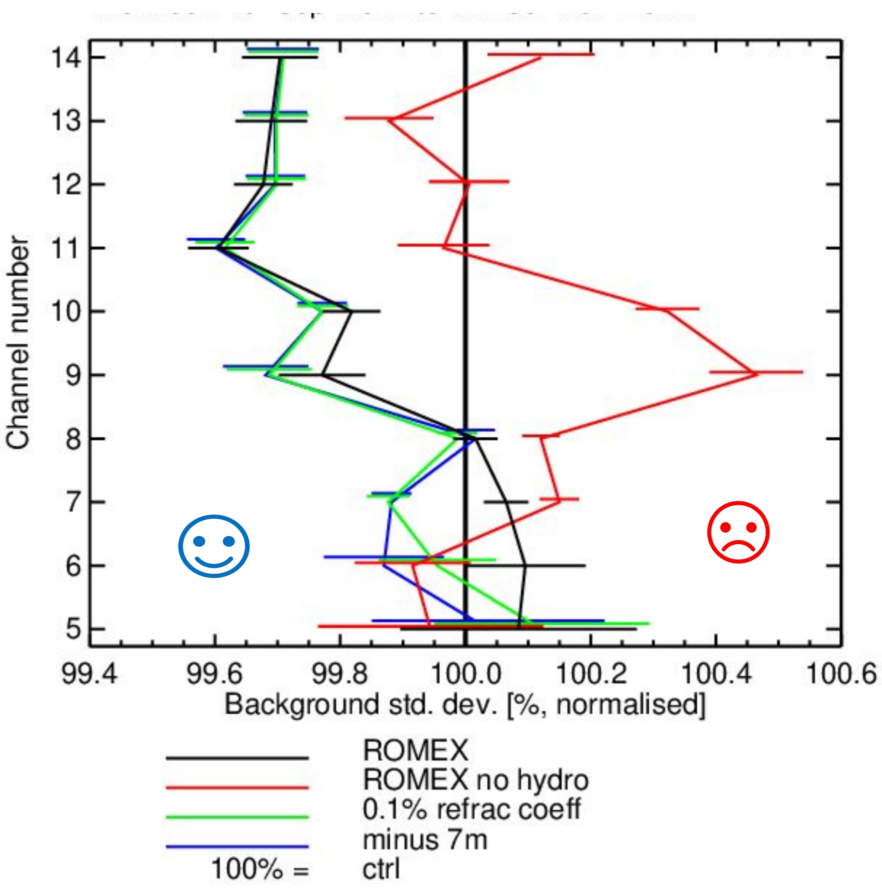
Impact on short-range forecasts (12h):

Change in std dev in First Guess departures (globally)

Radiosonde temperature



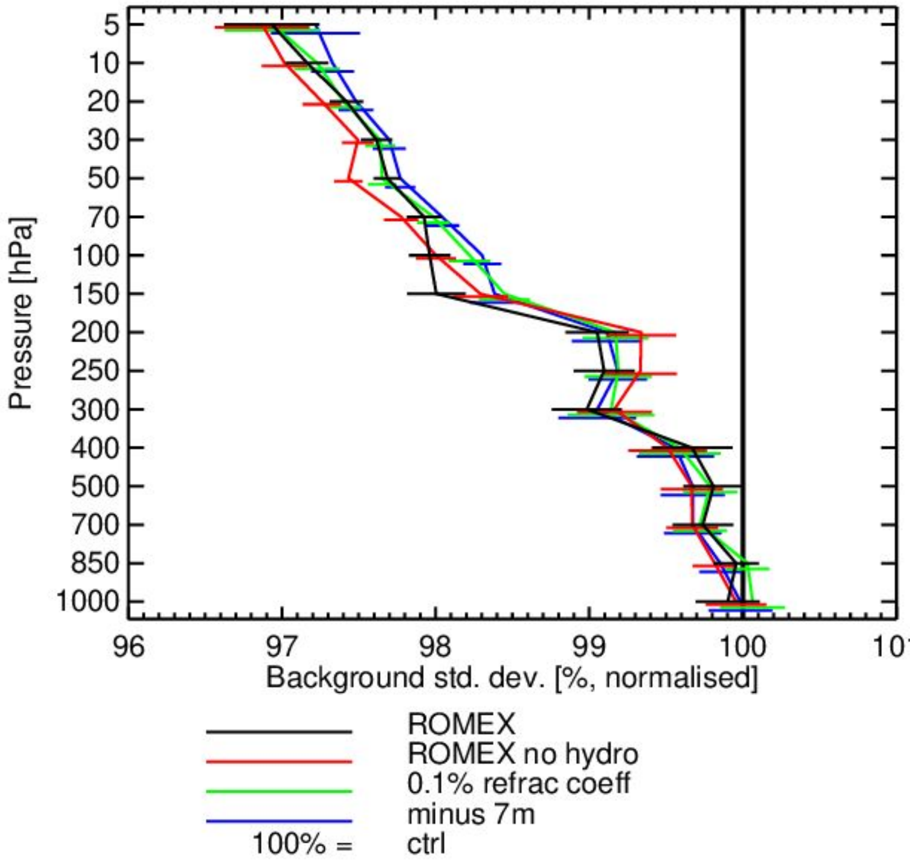
AMSU-A



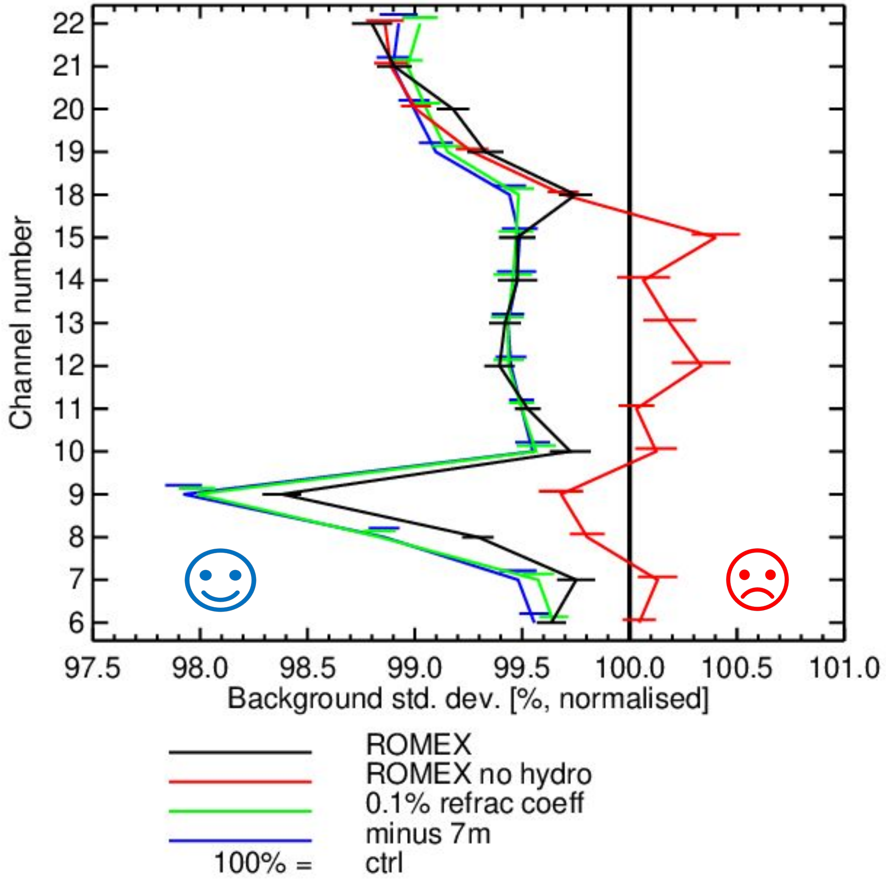
Impact on short-range forecasts (12h):

Change in std dev in First Guess departures (globally)

Wind observations

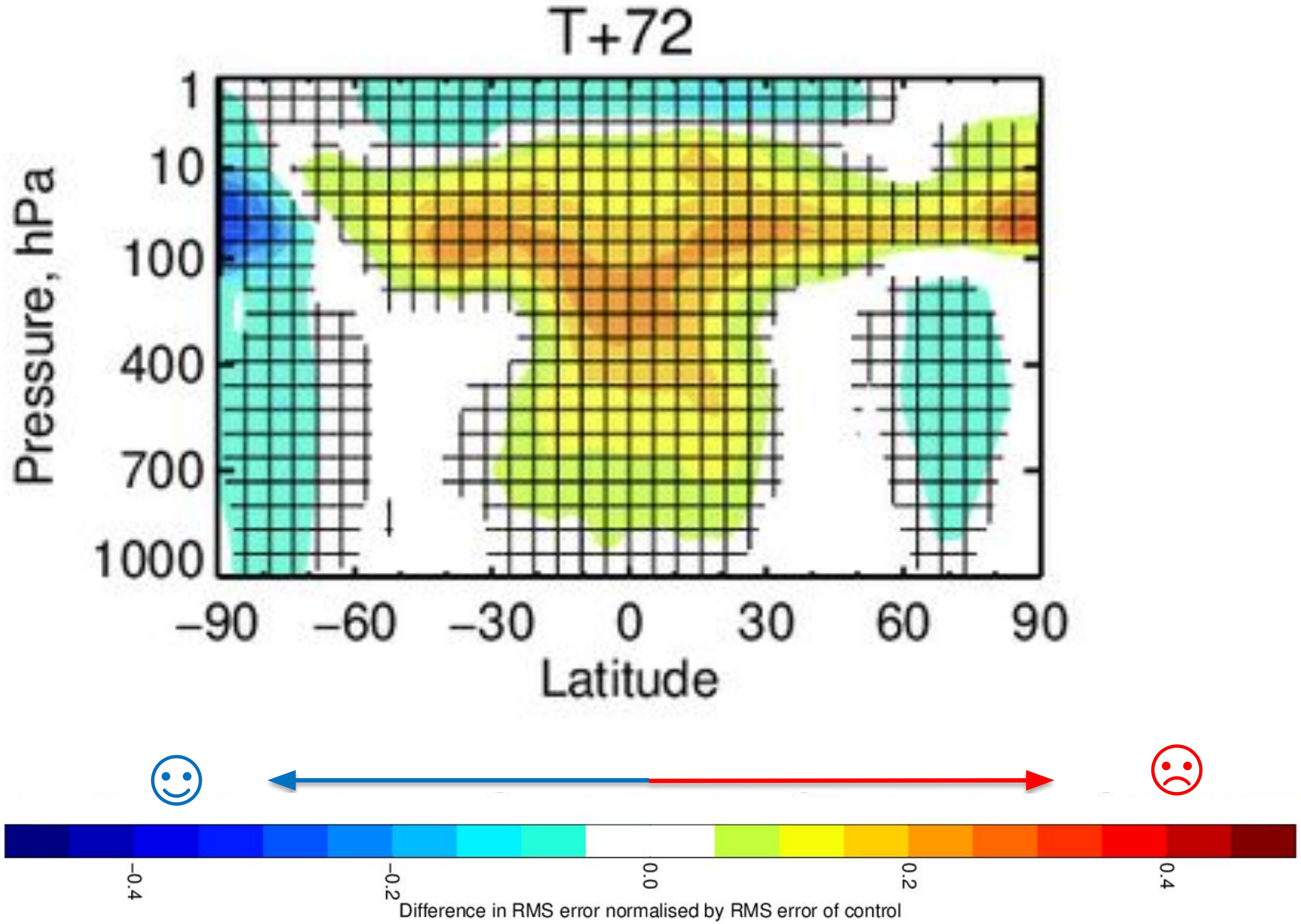


ATMS



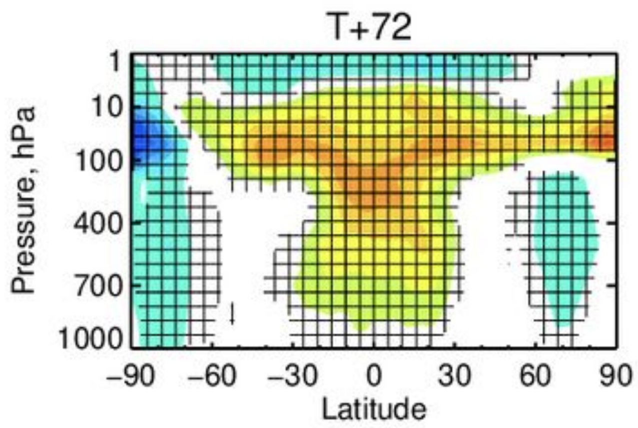
Increase in RMSE for Geopotential

ROMEX - control

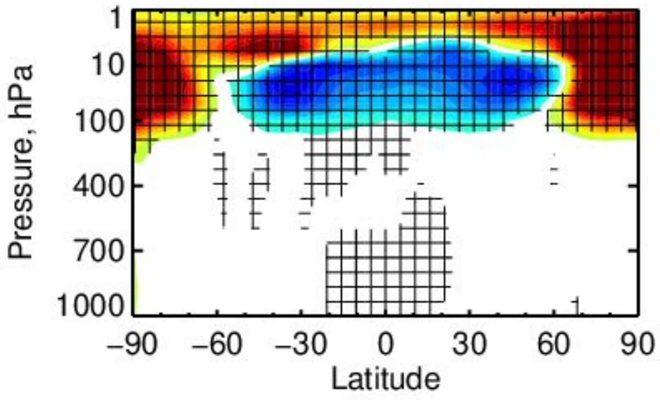


Change in RMSE for Geopotential

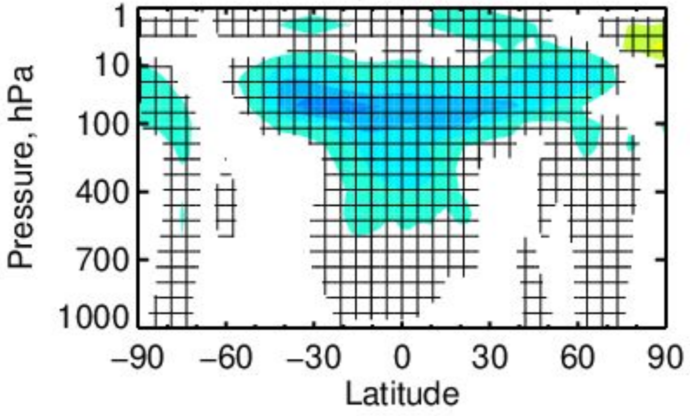
ROMEX - control



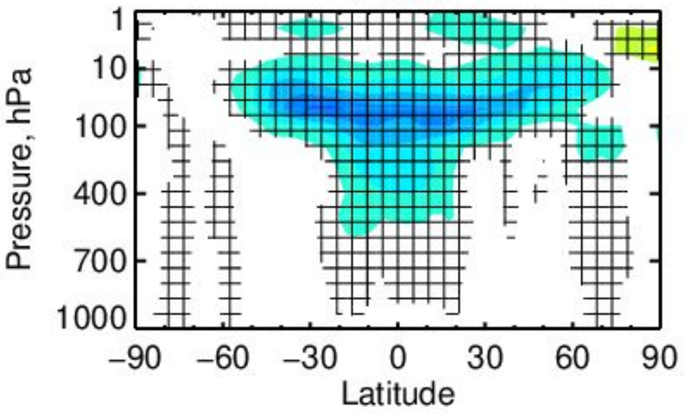
ROMEX no hydro - control

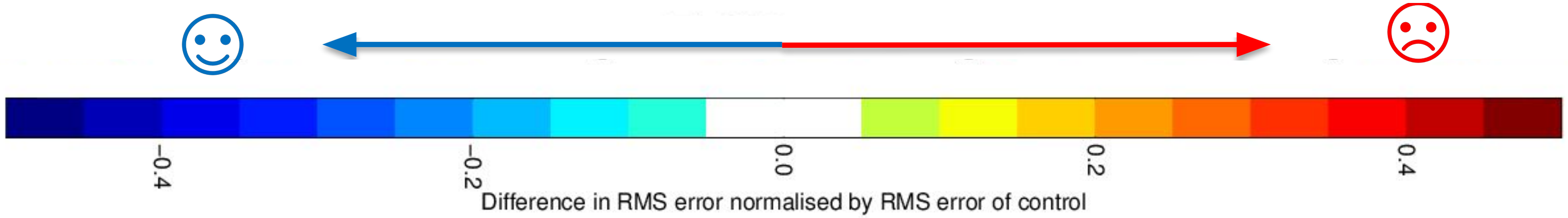


0.1% refrac coeff - control



Minus 7m - control



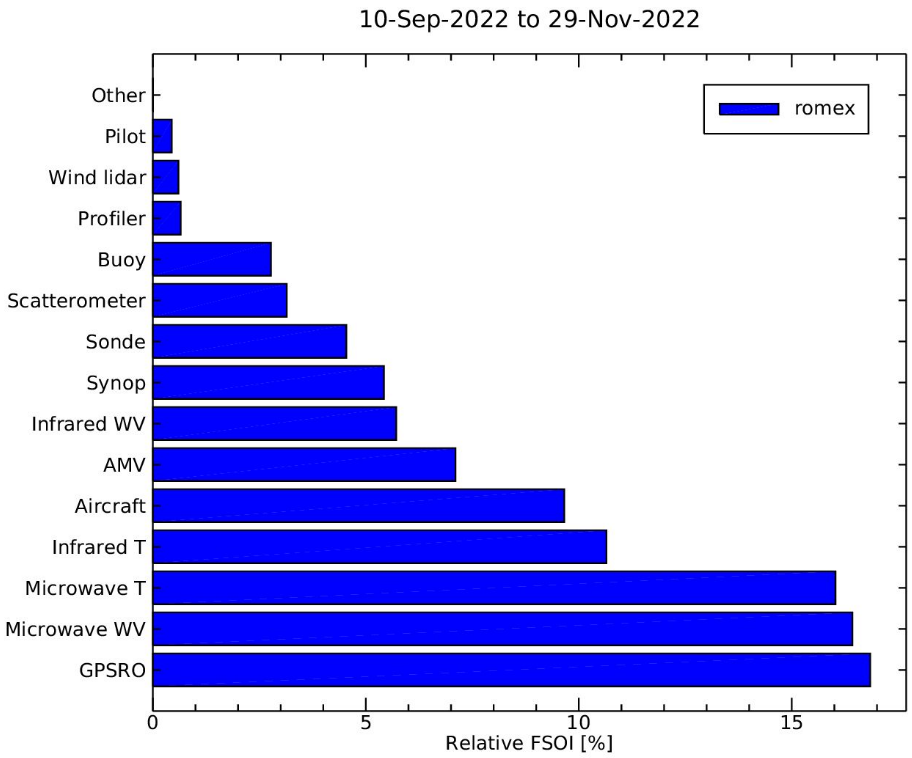


Summary Sensitivity Studies

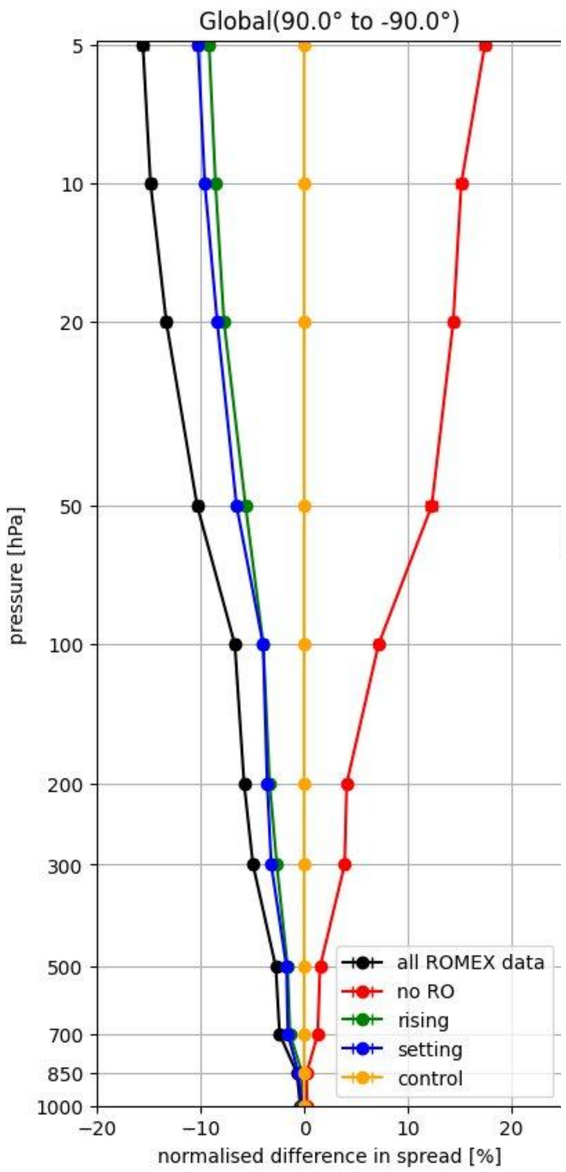
- ROMEX: Good impact on temperature, geopotential and wind in short-range and medium-range forecast scores in terms of std dev.
- Slight increase in mean error for Geopotential height (2- 5 m), caused by cooler background
- Sensitivity studies:
  - Excluding bending angles from lowest height levels doesn't change the picture
  - Not allowing hydrostatic tail in FO also not the ideal solution
  - Allowing small adjustments of refrac coeff. and height conversion in FO seem to the best way forward
- Open questions:
  - Do we think the small mean change in geopotential/temperature error needs to be investigated further?
  - Are bending angles measurements accurate enough to justify an 0.1% adjustment inside the FO?

Don’t forget…

FSOI

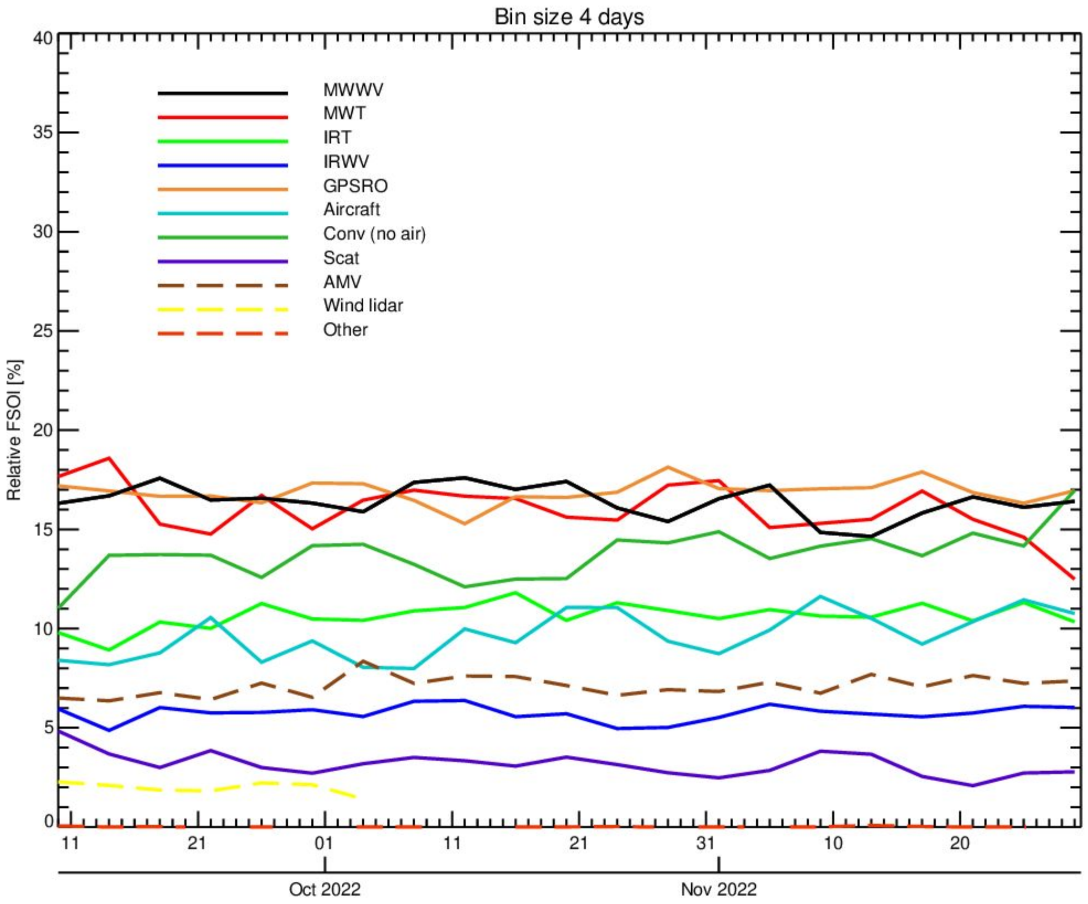


EDA for temperature, T+12h

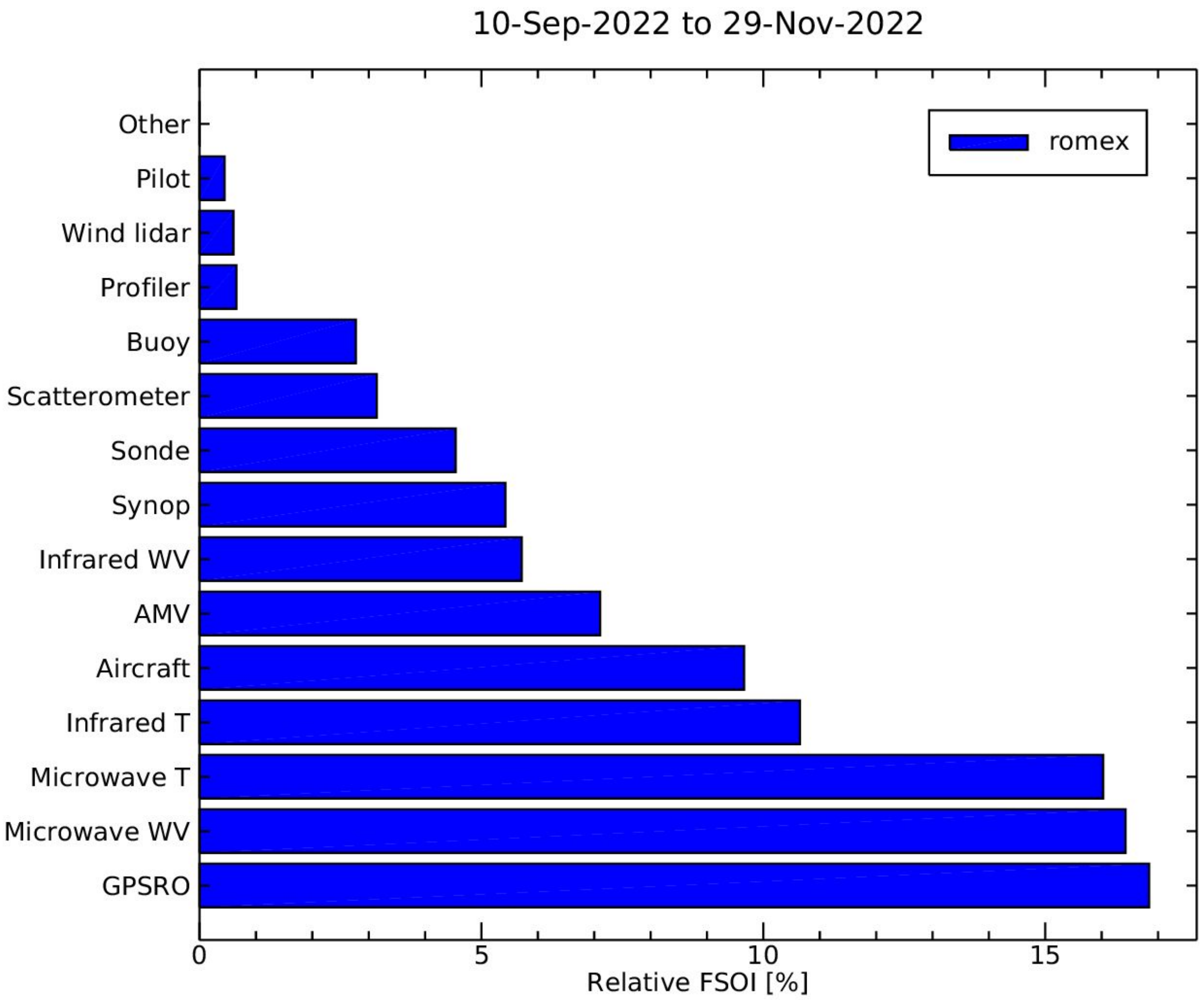


Backup

FSOI

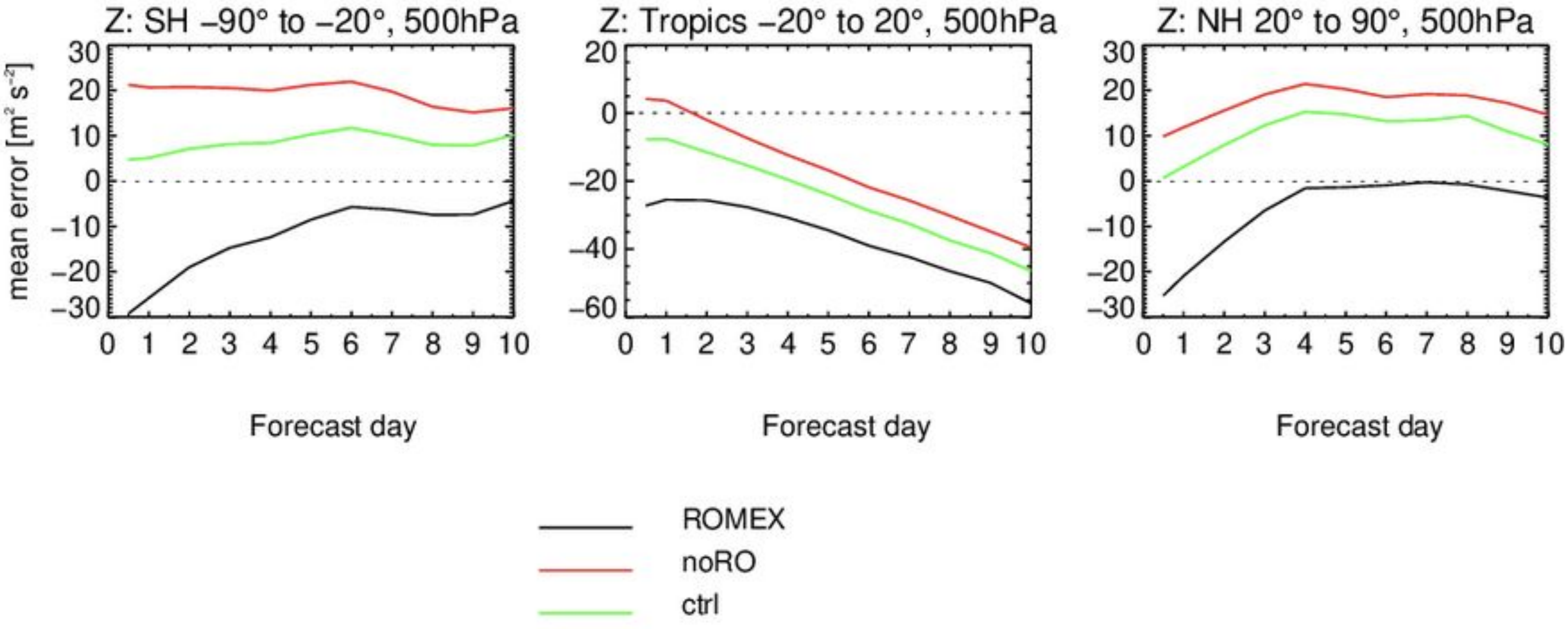


Bin size 4 days
MWWV
MWT
IRT
IRWV
GPSRO
Aircraft
Conv (no air)
Scat
AMV
Wind lidar
Other
Relative FSOI [%]
0
5
10
15
20
25
30
35
40
11
21
01
11
21
31
10
20
Oct 2022
Nov 2022



10-Sep-2022 to 29-Nov-2022
romex
Other
Pilot
Wind lidar
Profiler
Buoy
Scatterometer
Sonde
Synop
Infrared WV
AMV
Aircraft
Infrared T
Microwave T
Microwave WV
GPSRO
0
5
10
15
Relative FSOI [%]

Change in mean error for geopotential@500hPa



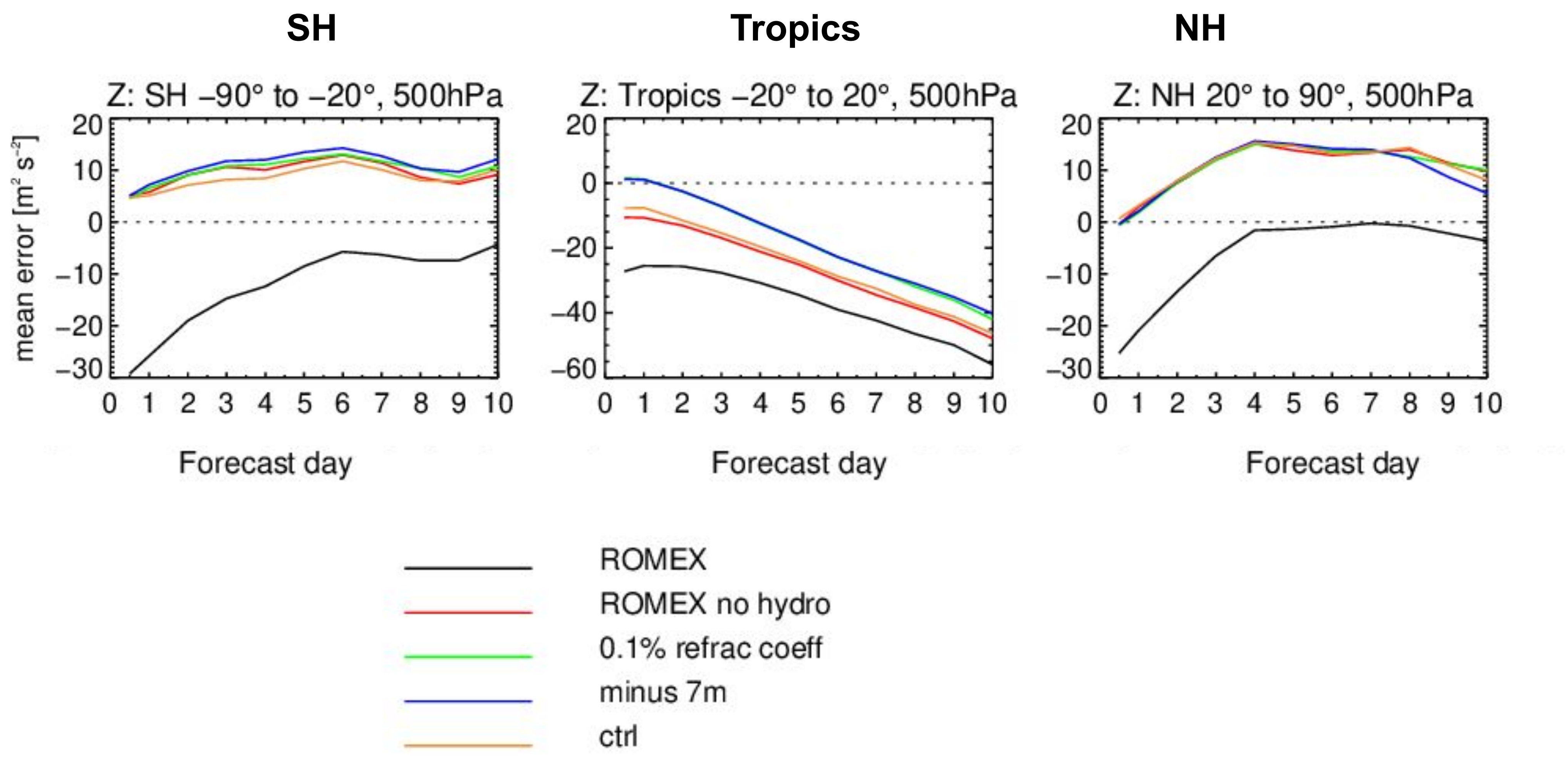
From Rick Anthes collection about refractivity calculation

Table 2 Source	k_1	k_2	k_3	Comments
Cucurull 2010 Exp. PREXPB	77.6890	71.2952	3.75463	Basis for NCEP GSI/GSF model system. Rueger 2002
Xuanli Li 5-12-24 GFS operational	77.6890	71.2952	3.75463	Same as NCEP
M. Murphy (5-11-24) GMAO V1	77.6890	71.2952	3.75463	Same as NCEP
Taiwan CWA	77.6890	71.2952	3.75463	Same as NCEP
ECMWF	77.643	71.2952	3.75463	Sean Healy 5-13-24

- Equation for refractivity N in terms of dry pressure P_d and water vapor pressure e:
- $N = k_1 P_d / T + k_2 e/T + k_3 e/T^2$

The values of k_1, k_2, and k_3 used in different forward models is shown in Table 2. Many models use this form and the coefficients in Cucurull 2010 Exp. PREXB

Change in mean error for geopotential@500hPa



Change in RMSE for Geopotential forecast error @ 500hPa