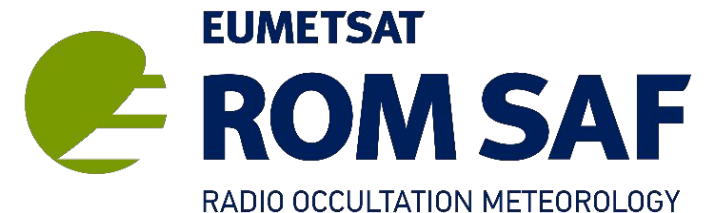


Sensitivity to the RO observation operator when assimilating 35,000 radio occultations per day during ROMEX

Katrin Lonitz

katrin.lonitz@ecmwf.int



Background

Setup

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

Verification against operational analysis and observations

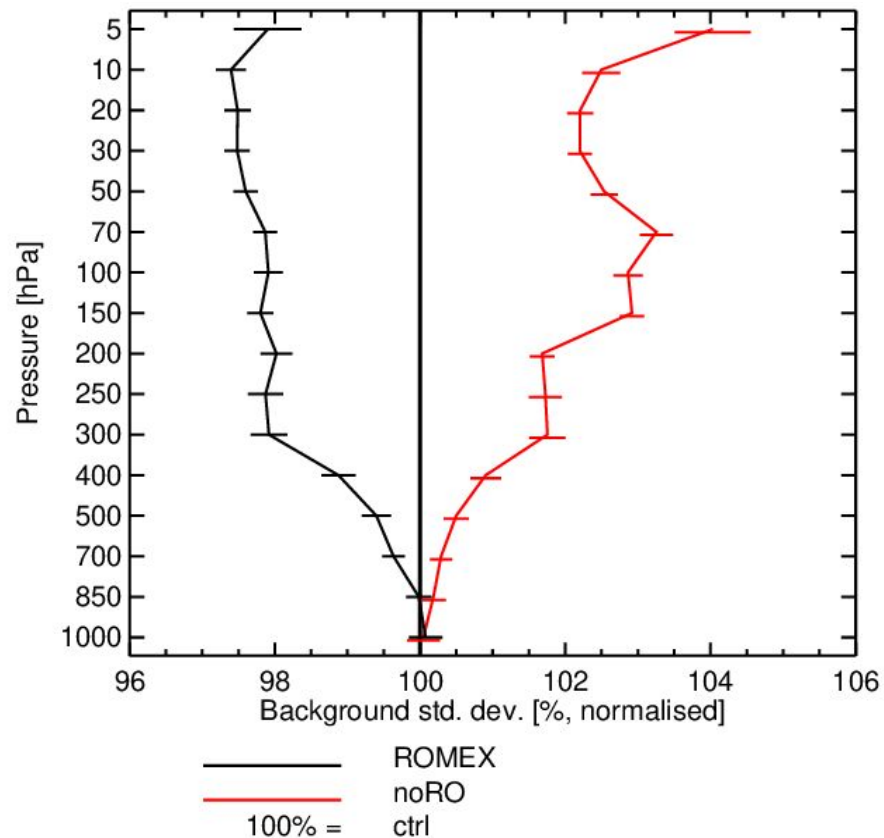
- Fits to independent observations
- Forecast scores (Std dev., RMSE, Anomaly correlation)
- Omit first 9 days in verification statistics to avoid including spinup issues

Experiments

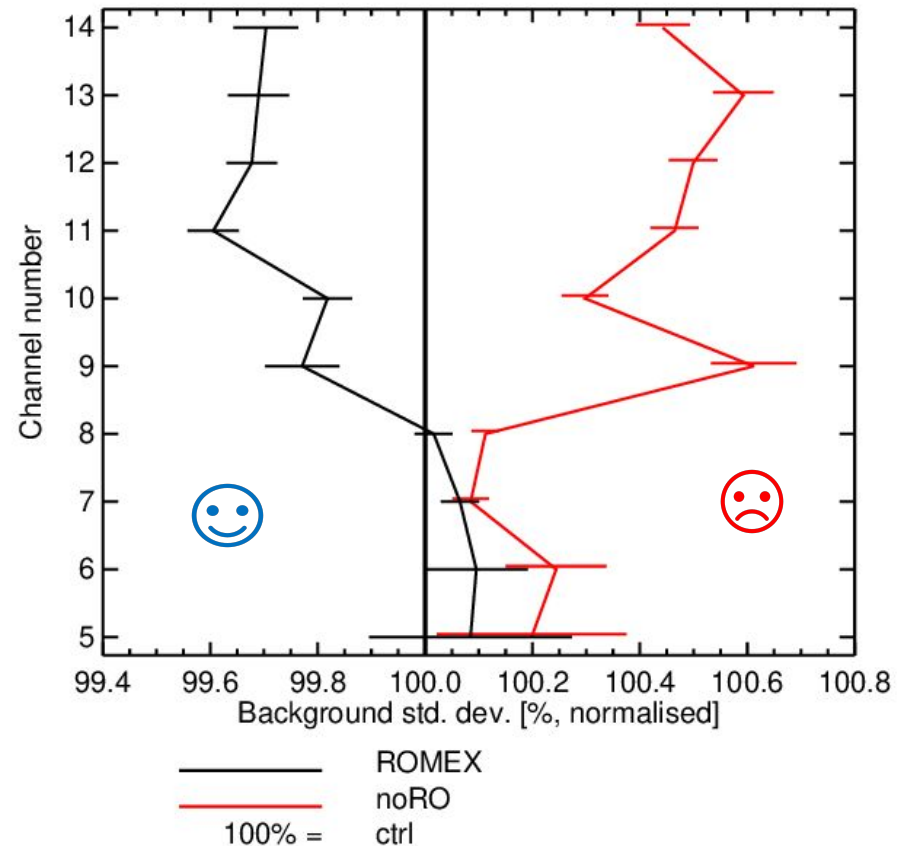
id	description
ctrl	Baseline (all GNSS-RO data excl. commercial and Chinese data)
ROMEX	All ROMEX data
noRO	No GNSS-RO data

Impact on short-range forecasts (12h): Change in std dev in First Guess departures (globally)

Radiosonde temperature

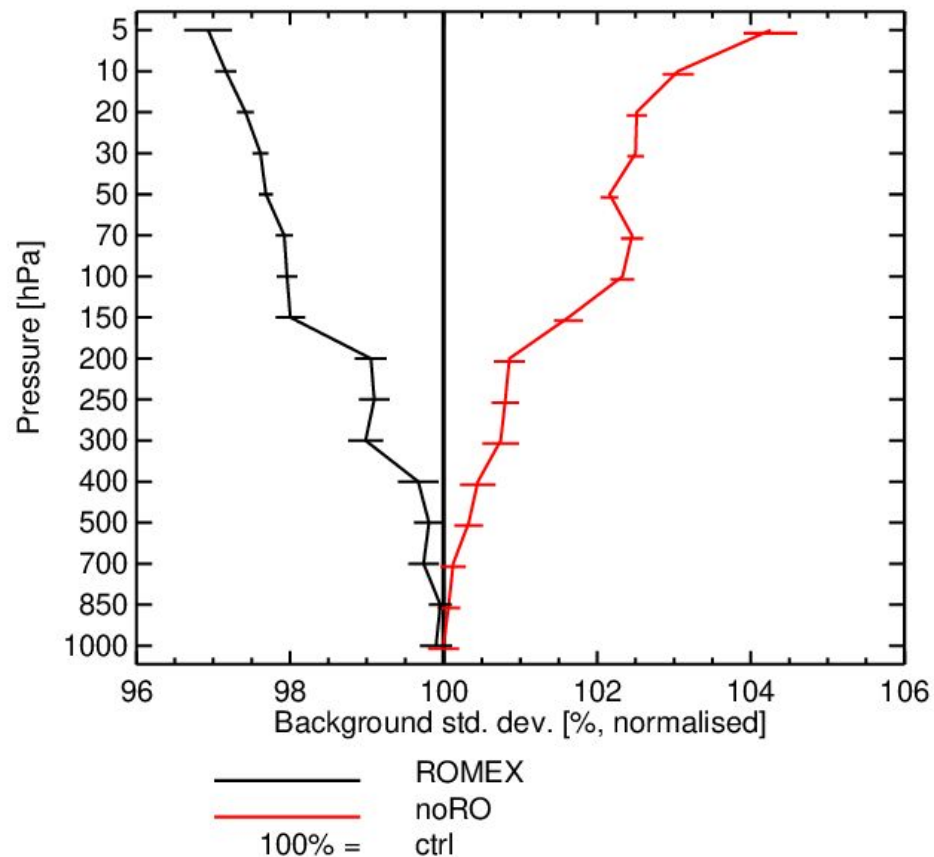


AMSU-A

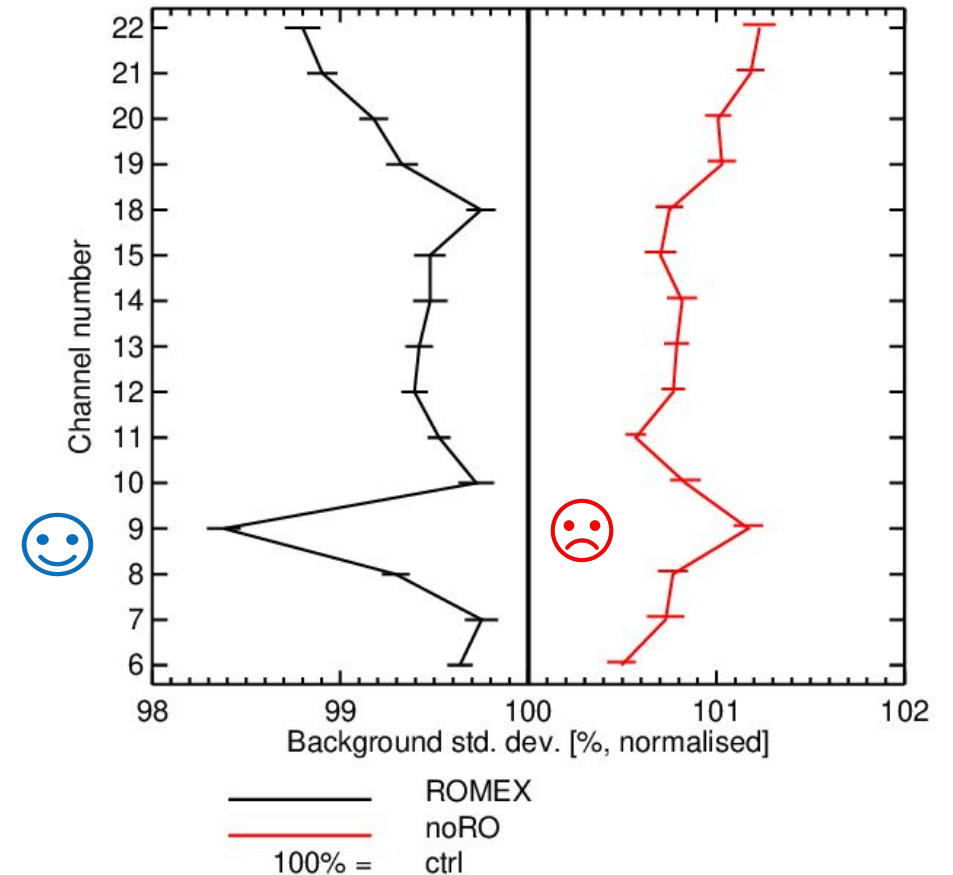


Impact on short-range forecasts (12h): Change in std dev in First Guess departures (globally)

Wind observations



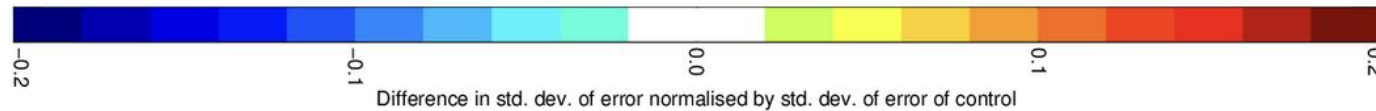
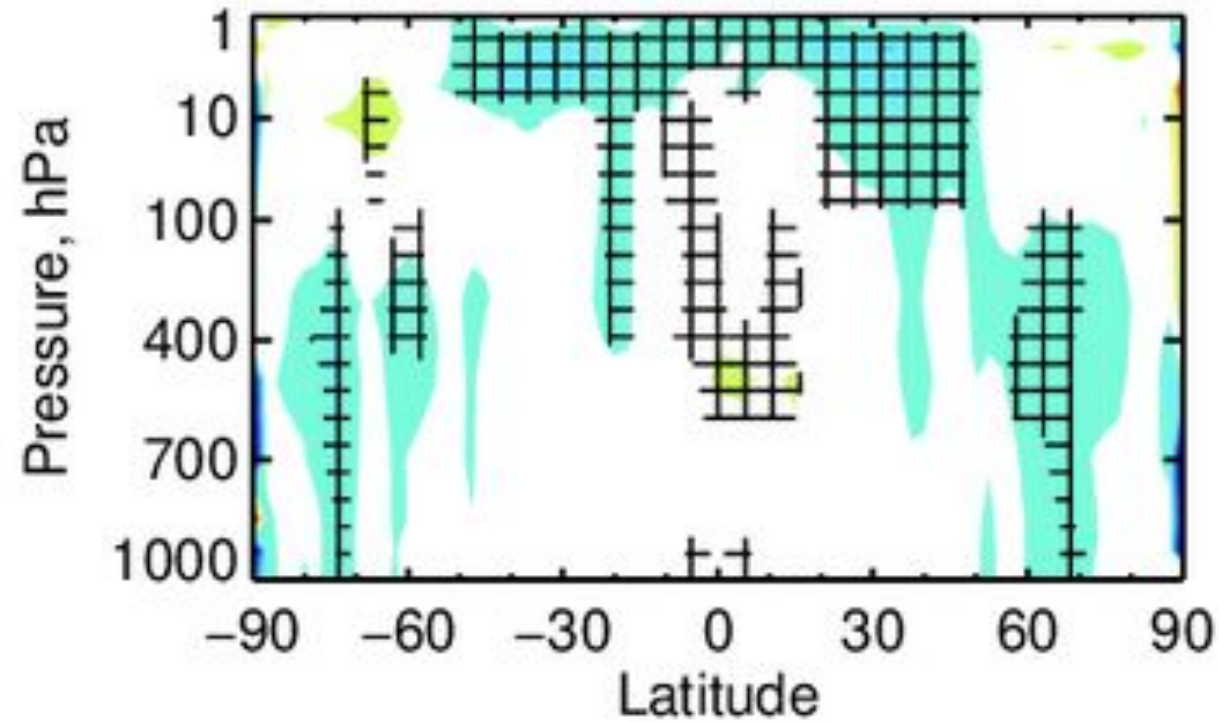
ATMS



Decrease in Std dev for Geopotential forecast error

ROMEX - control

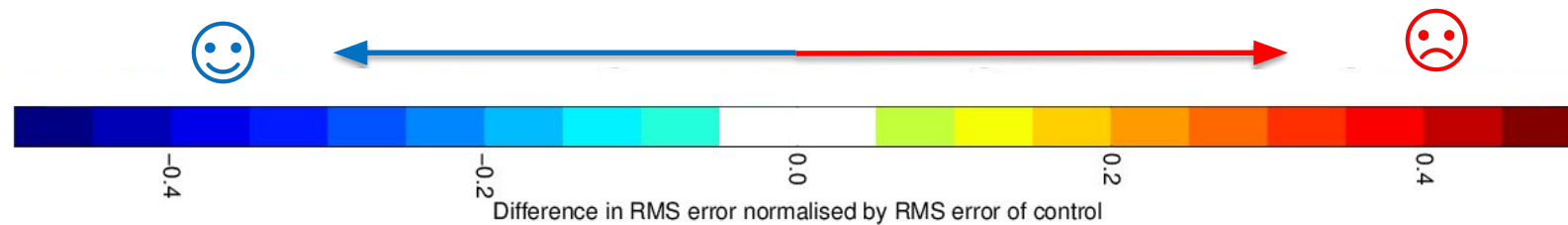
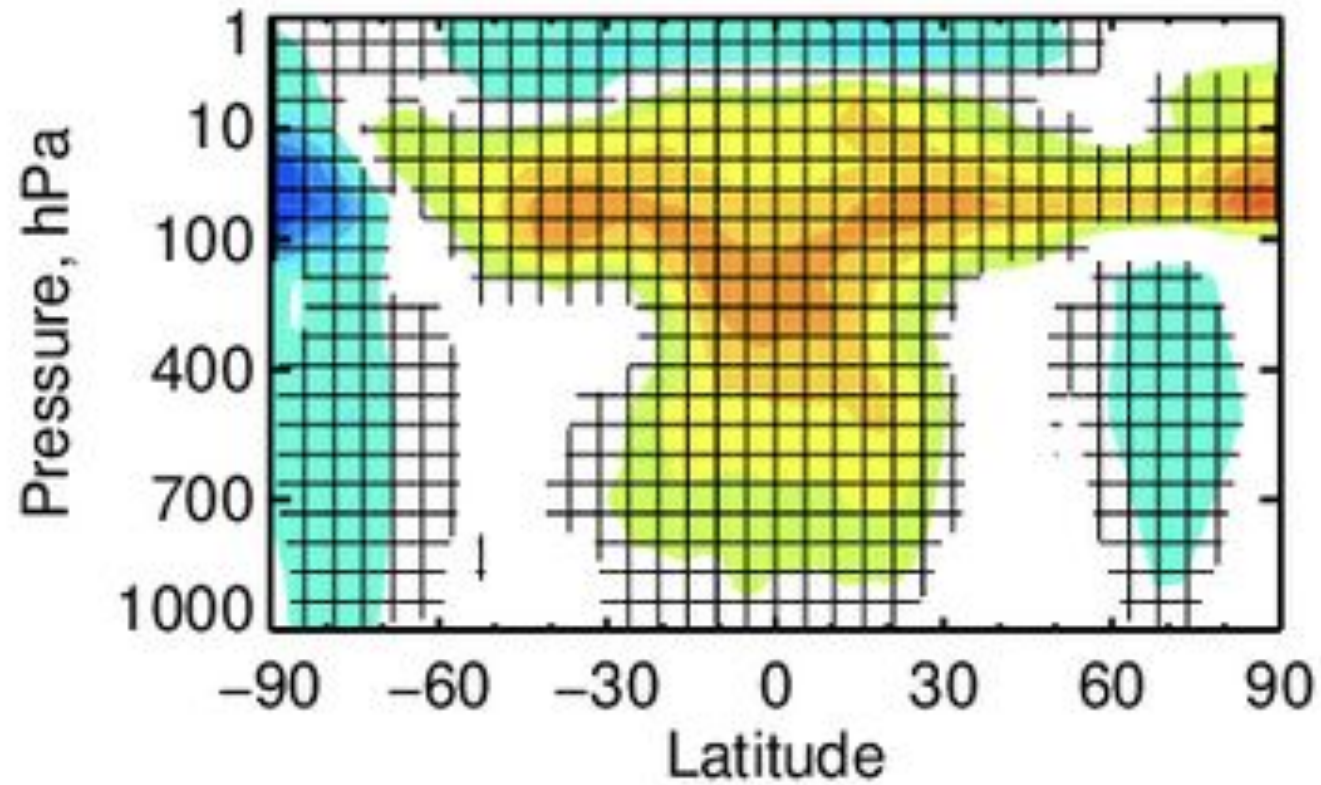
T+72



Increase in RMSE for Geopotential

ROMEX - control

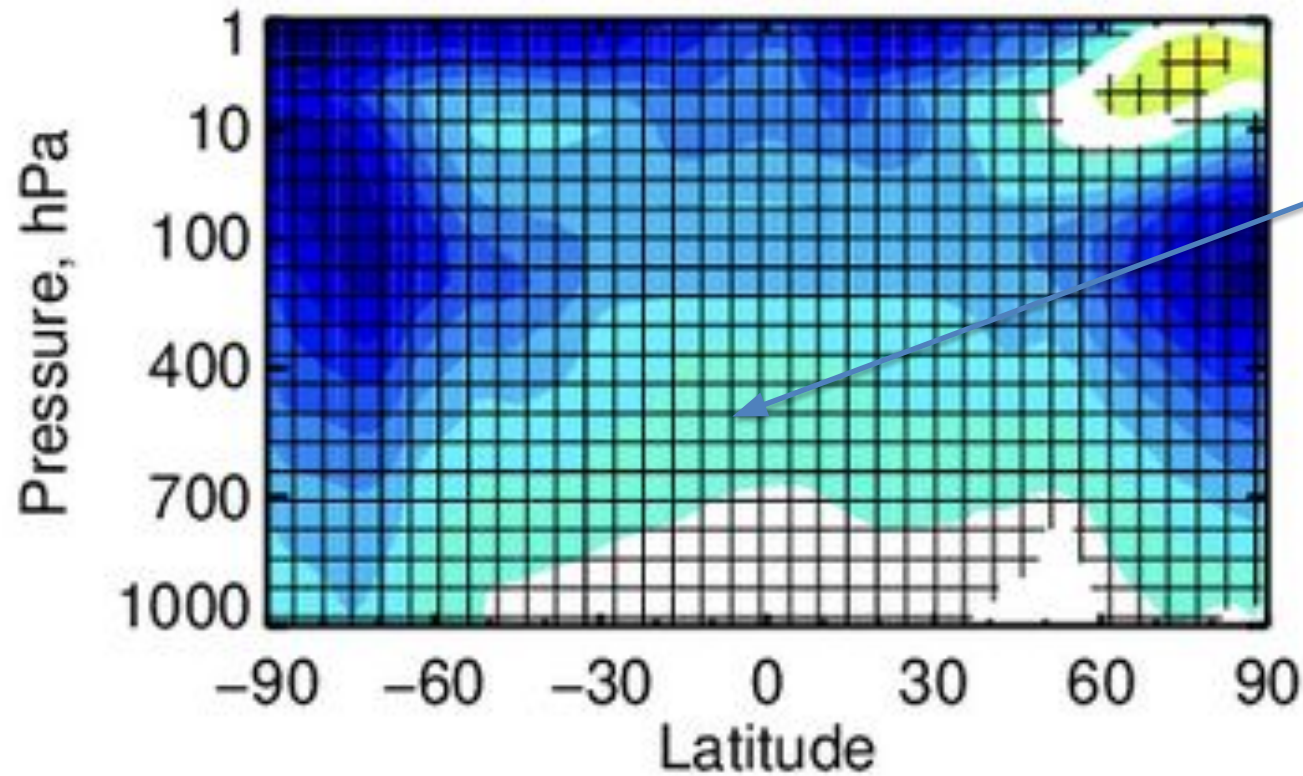
T+72



Mean change in geopotential

ROMEX - control

T+72

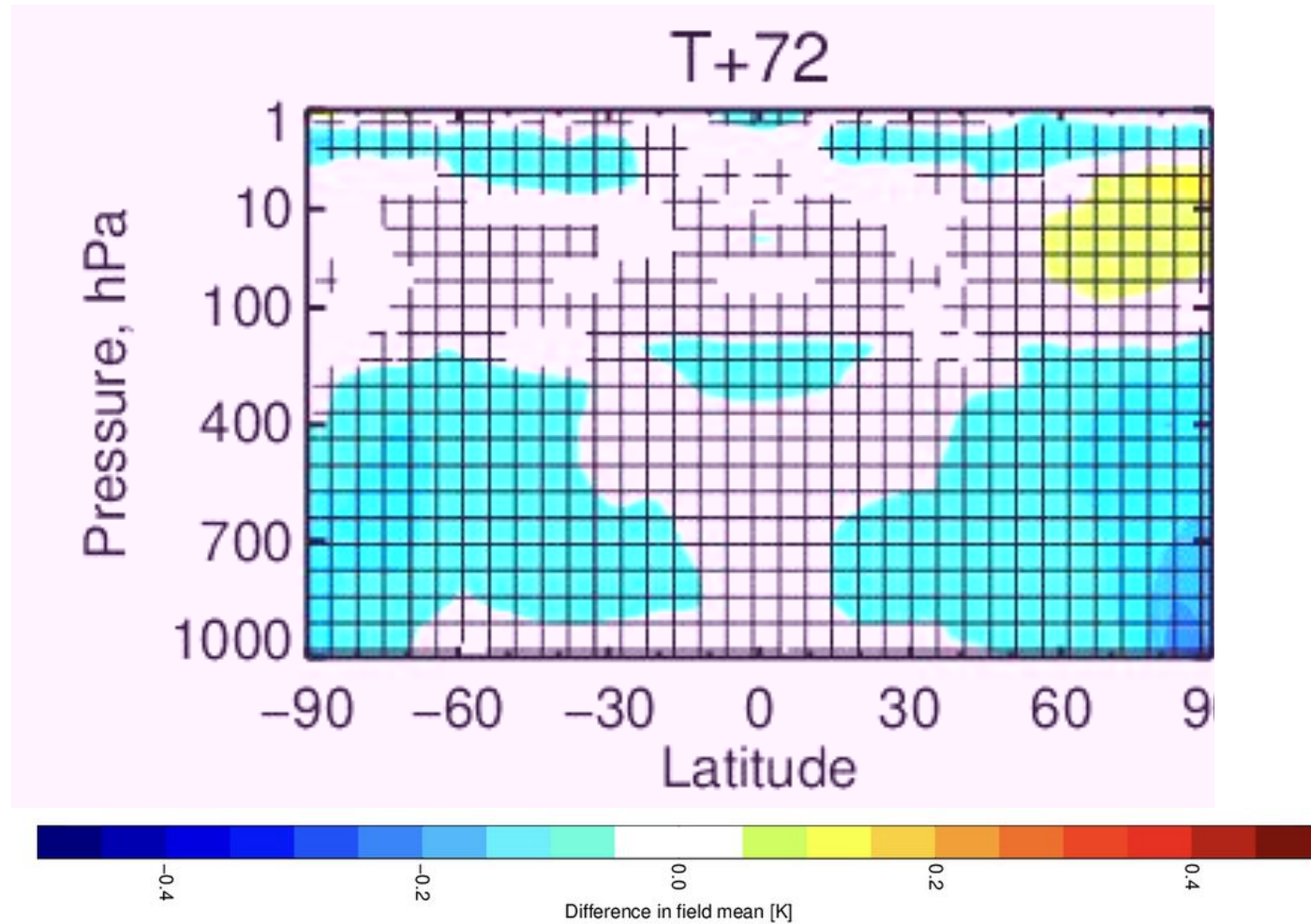


about 2-8 m change
in geopotential height

e.g. @ 500 hPa:
geopotential height $\sim 5.75 \text{ km}$
6m change in $z_g \cong 0.1\%$

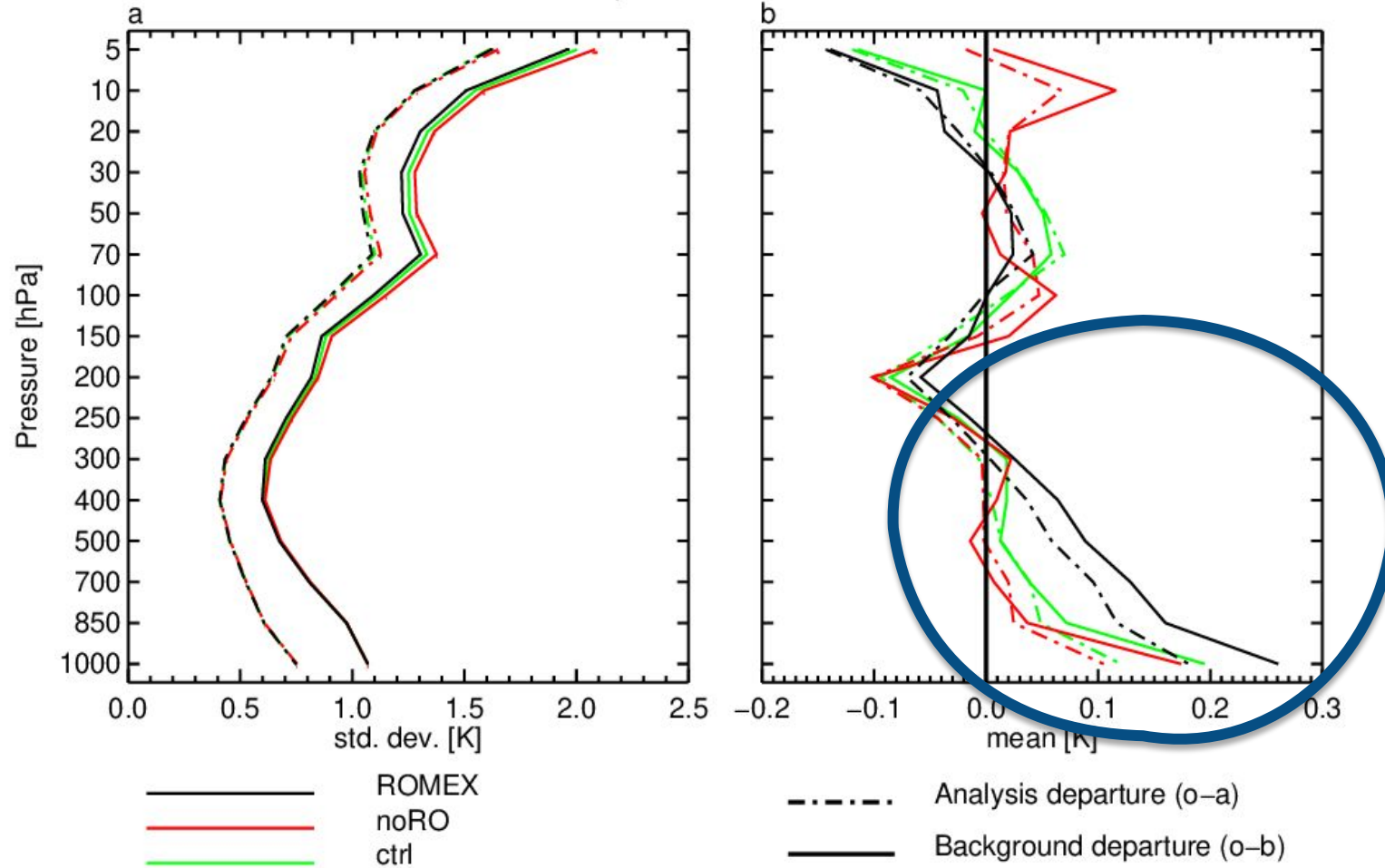
mean change in temperature

ROMEX - control



FGdep for Radiosonde Temperature

Instrument(s): TEMP – T Area(s): N.Hemis S.Hemis Tropics
 From 00Z 10-Sep-2022 to 12Z 30-Nov-2022



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 geopotential



EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

• **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

Sensitivity Experiments

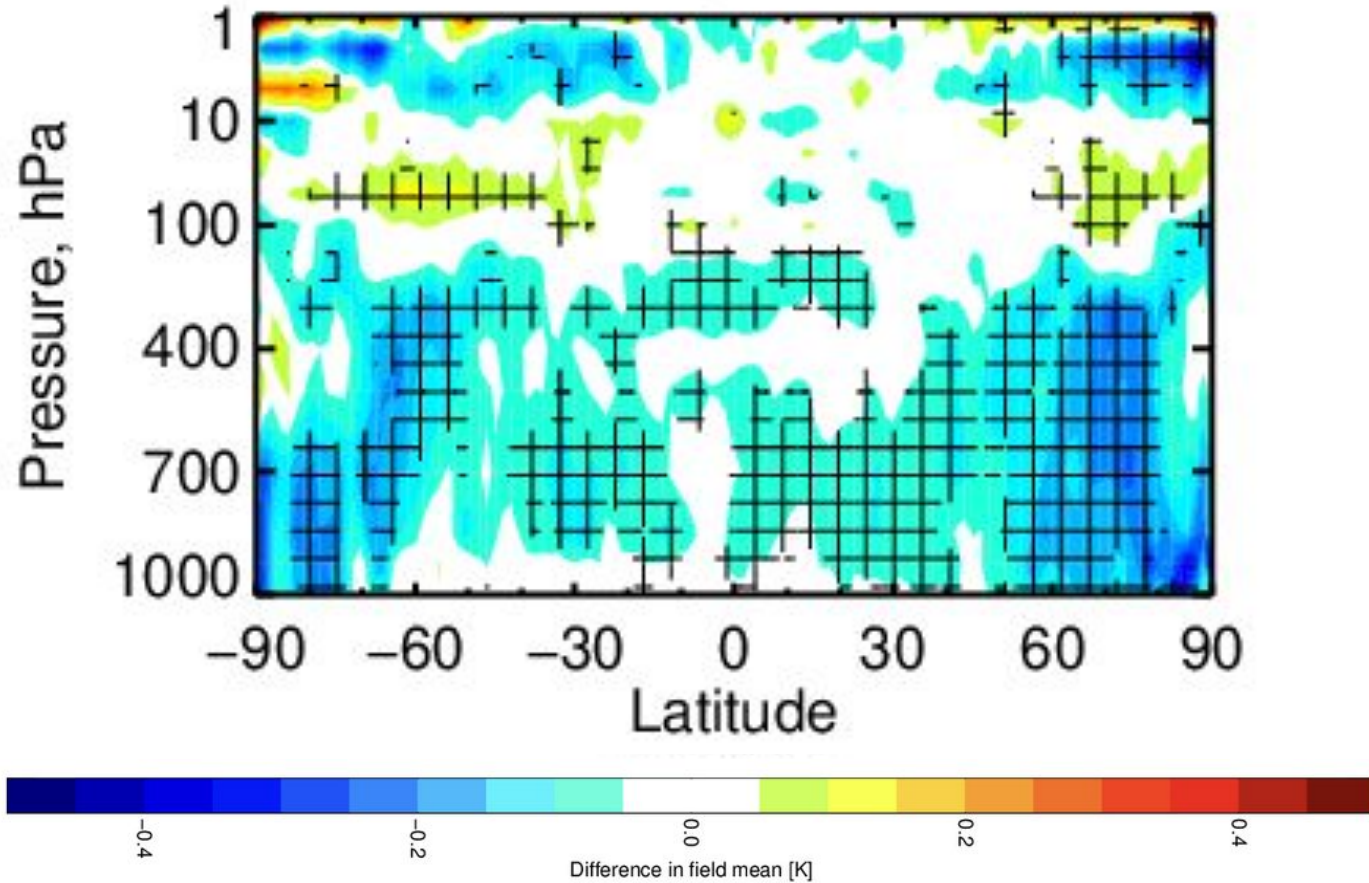
- small modifications of the GNSS-RO forward operator -

id	description
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

mean change in temperature

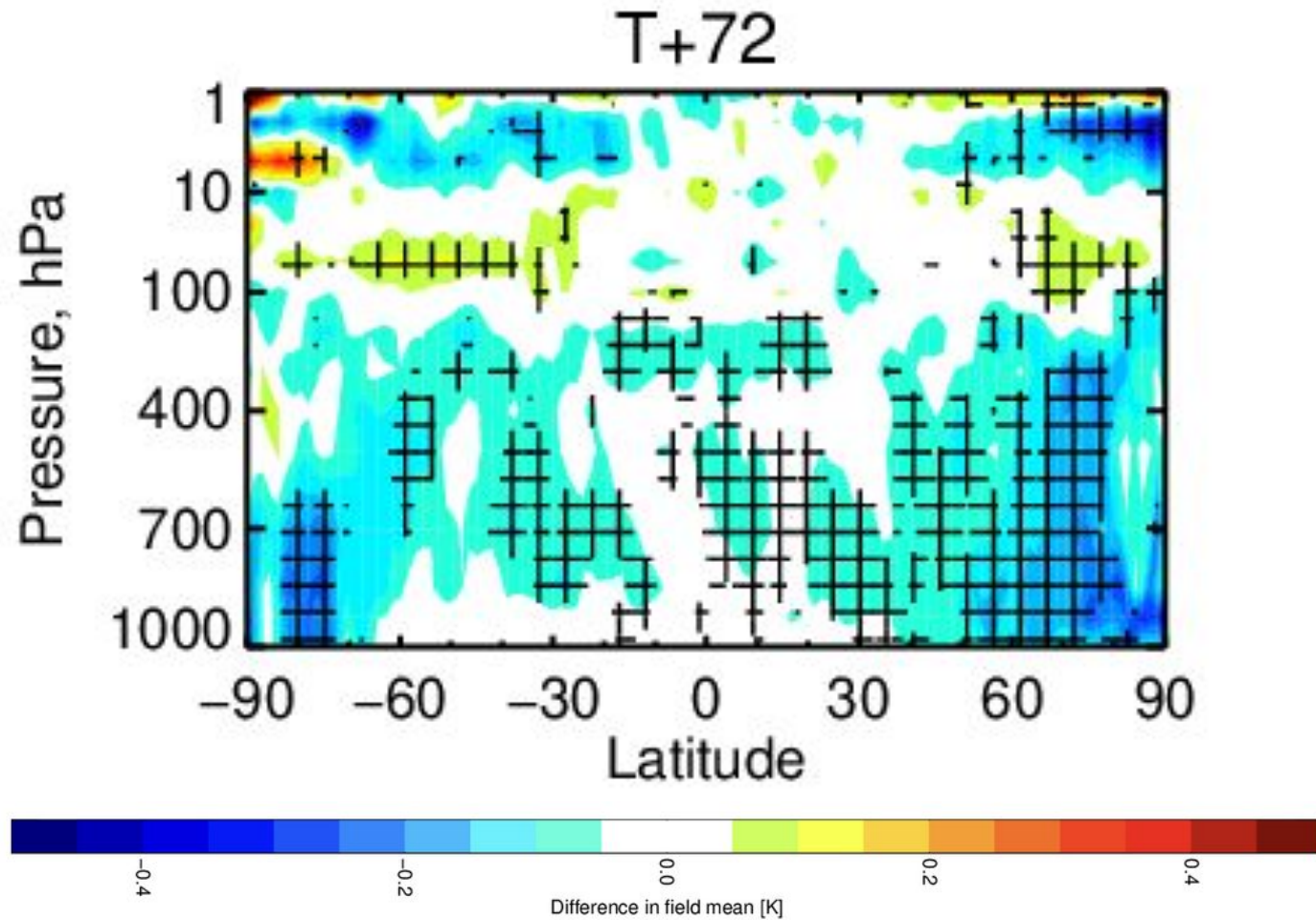
ROMEX - control

T+72



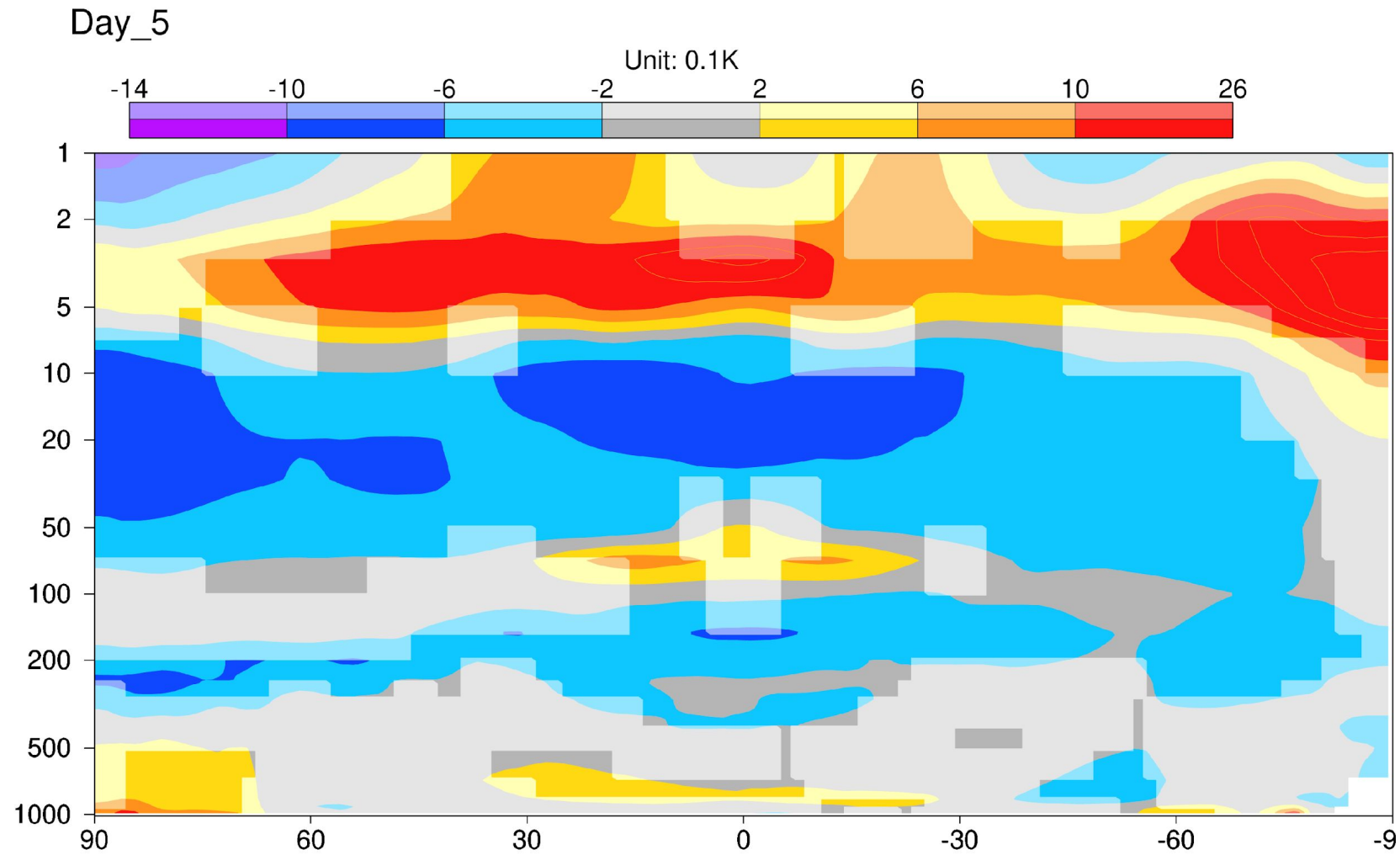
mean change in temperature

ROMEX no 5km - control



Biases in stratosphere

Forecast Error. T Zonal-mean 180W-180E. Mean for MAM 2024. Deep colours = 5% sig. (AR1)



Sensitivity Experiments

- small modifications of the GNSS-RO forward operator -

id	description
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

Hydrostatic tail

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

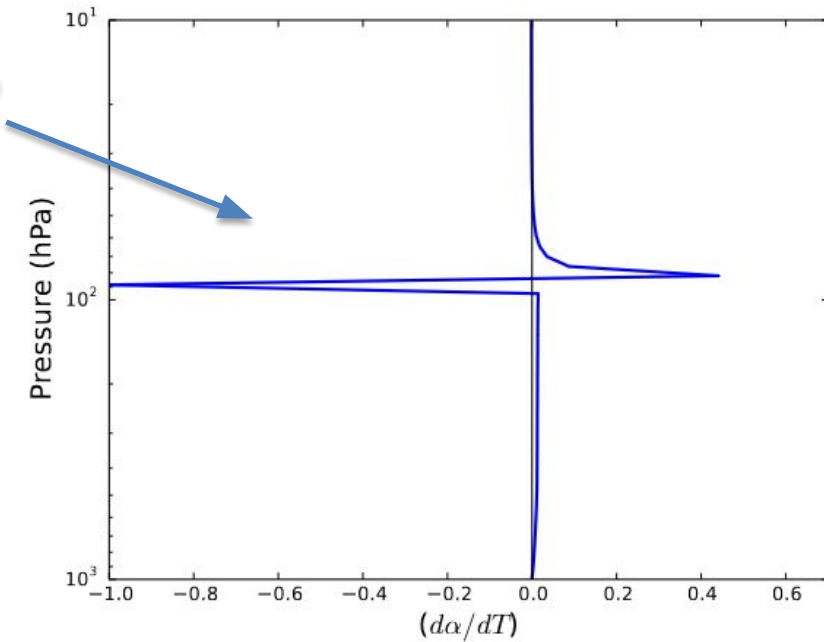


Figure 2: The temperature weighting function, $(\partial \alpha / \partial T)$, for stratospheric bending angle. The largest contributions are from the model levels directly above and below the observed tangent height. The long “hydrostatic” tail below the tangent point is caused by the sensitivity of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

Hydrostatic tail

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

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

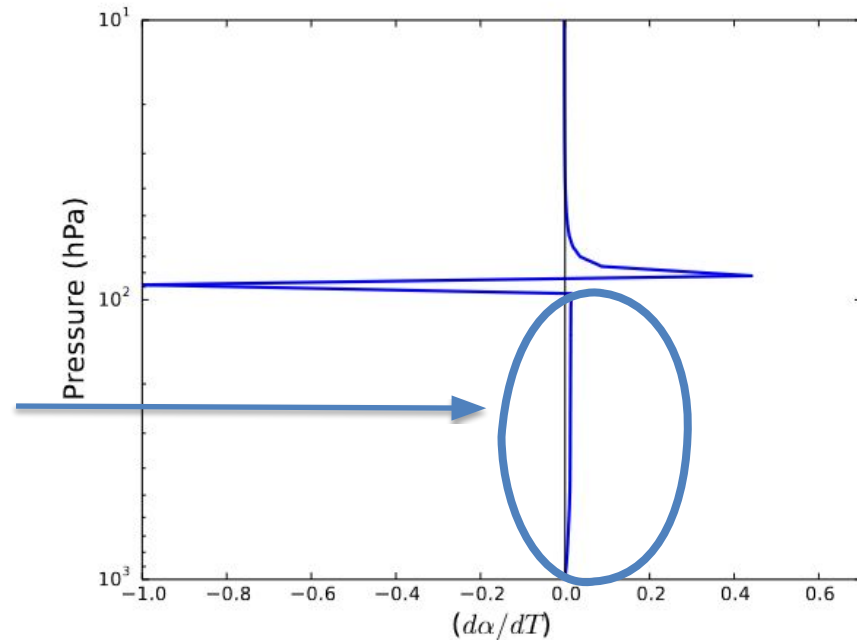


Figure 2: The temperature weighting function, $(\partial \alpha / \partial T)$, for stratospheric bending angle. The largest contributions are from the model levels directly above and below the observed tangent height. The long “hydrostatic” tail below the tangent point is caused by the sensitivity of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

Hydrostatic tail

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

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

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

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

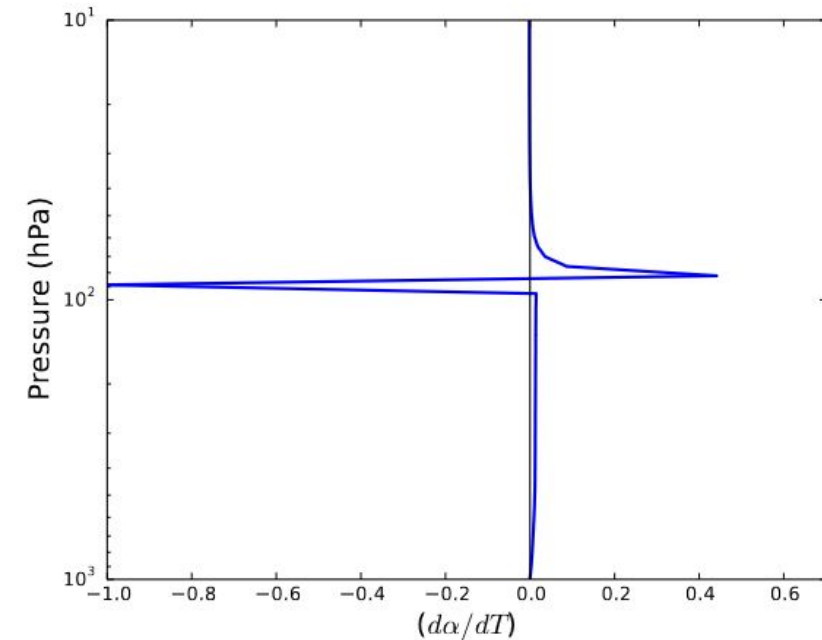


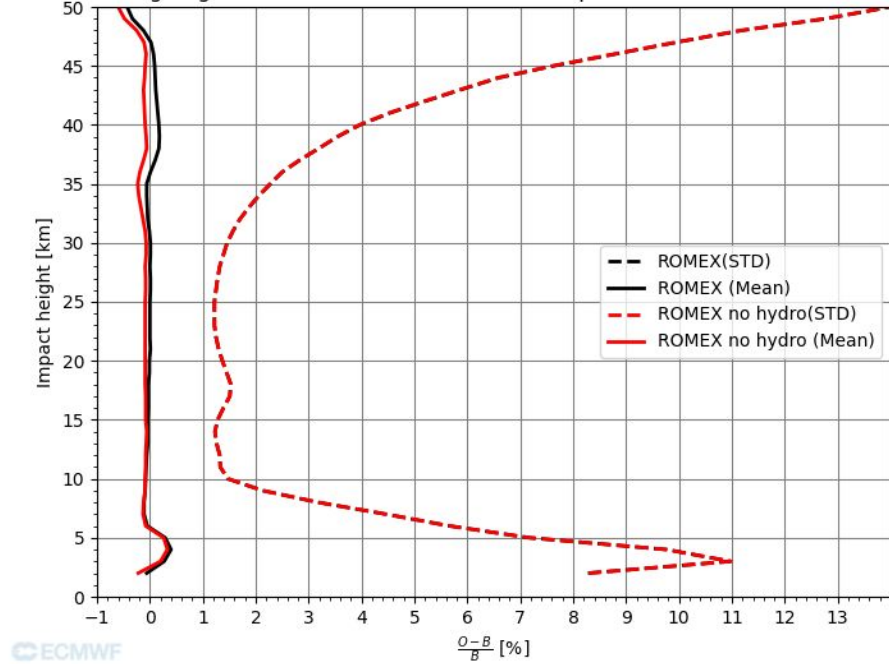
Figure 2: The temperature weighting function, $(\partial \alpha / \partial T)$, for stratospheric bending angle. The largest contributions are from the model levels directly above and below the observed tangent height. The long “hydrostatic” tail below the tangent point is caused by the sensitivity of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

Normalised FG dep for Spire data

testing no hydrostatic tail

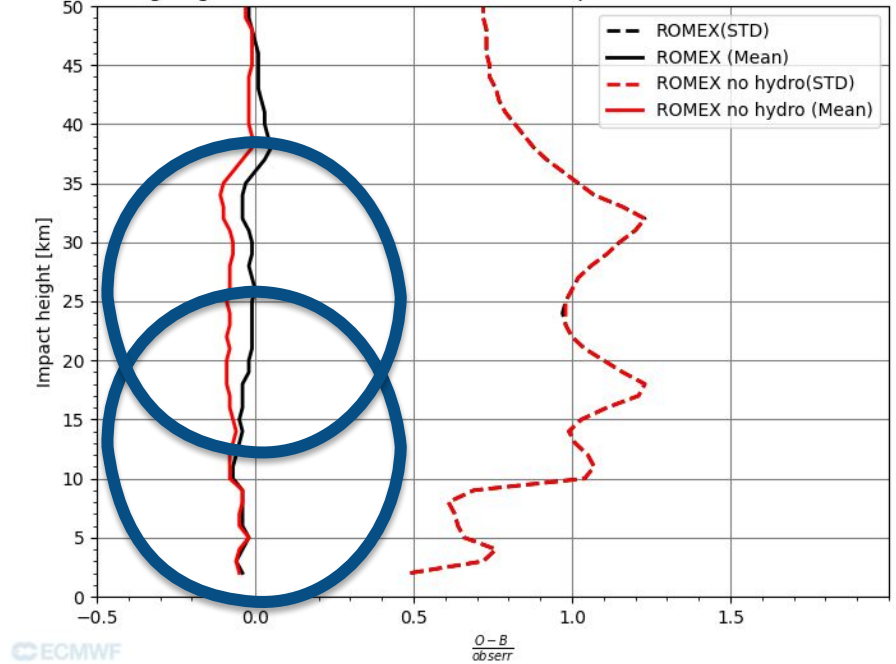
by
FG

Global Bending Angle Norm. Innovation Statistics for spire from 2022091000 to 2022092012



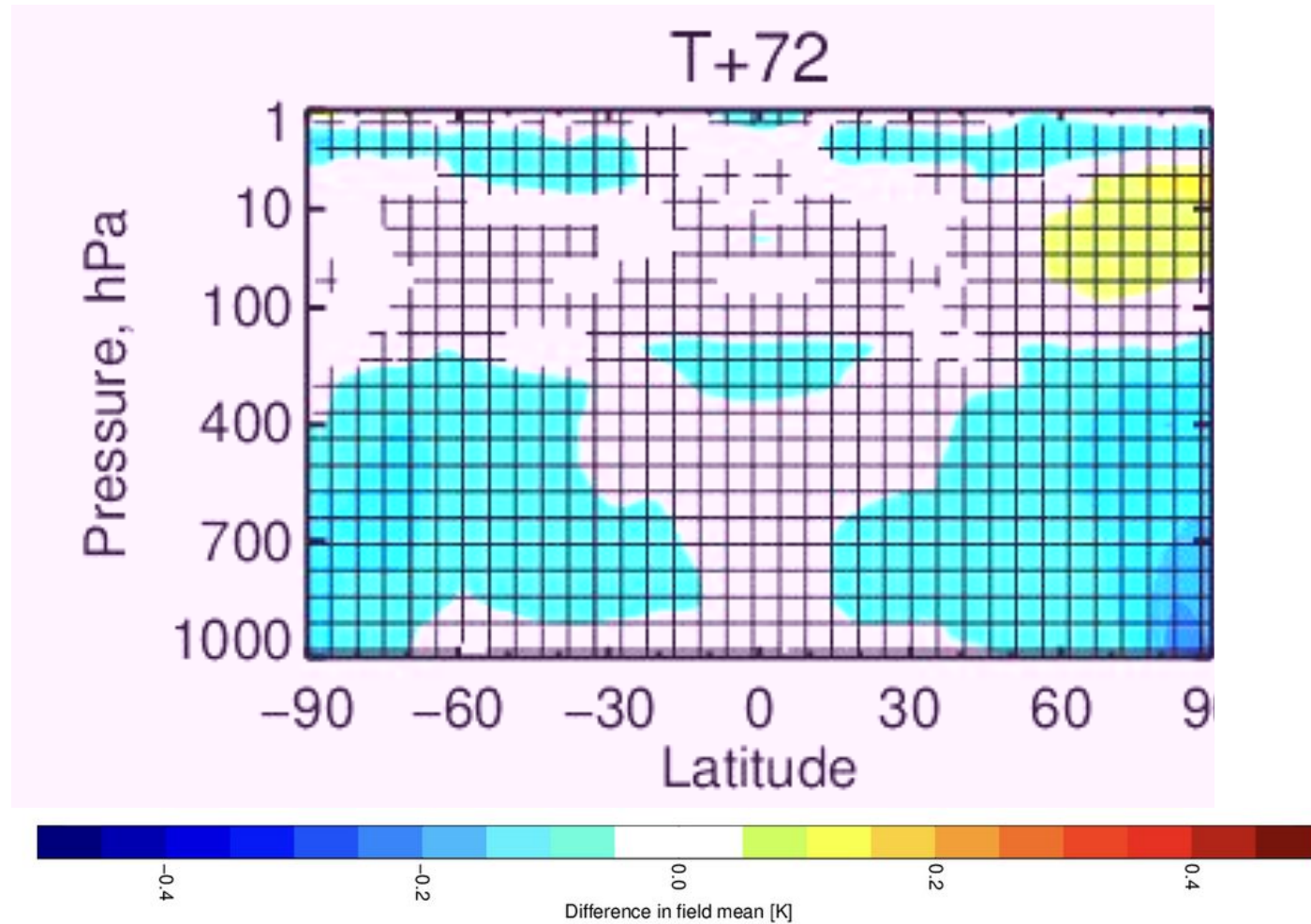
by obs error

Global Bending Angle Norm. Innovation Statistics for spire from 2022091000 to 2022092012



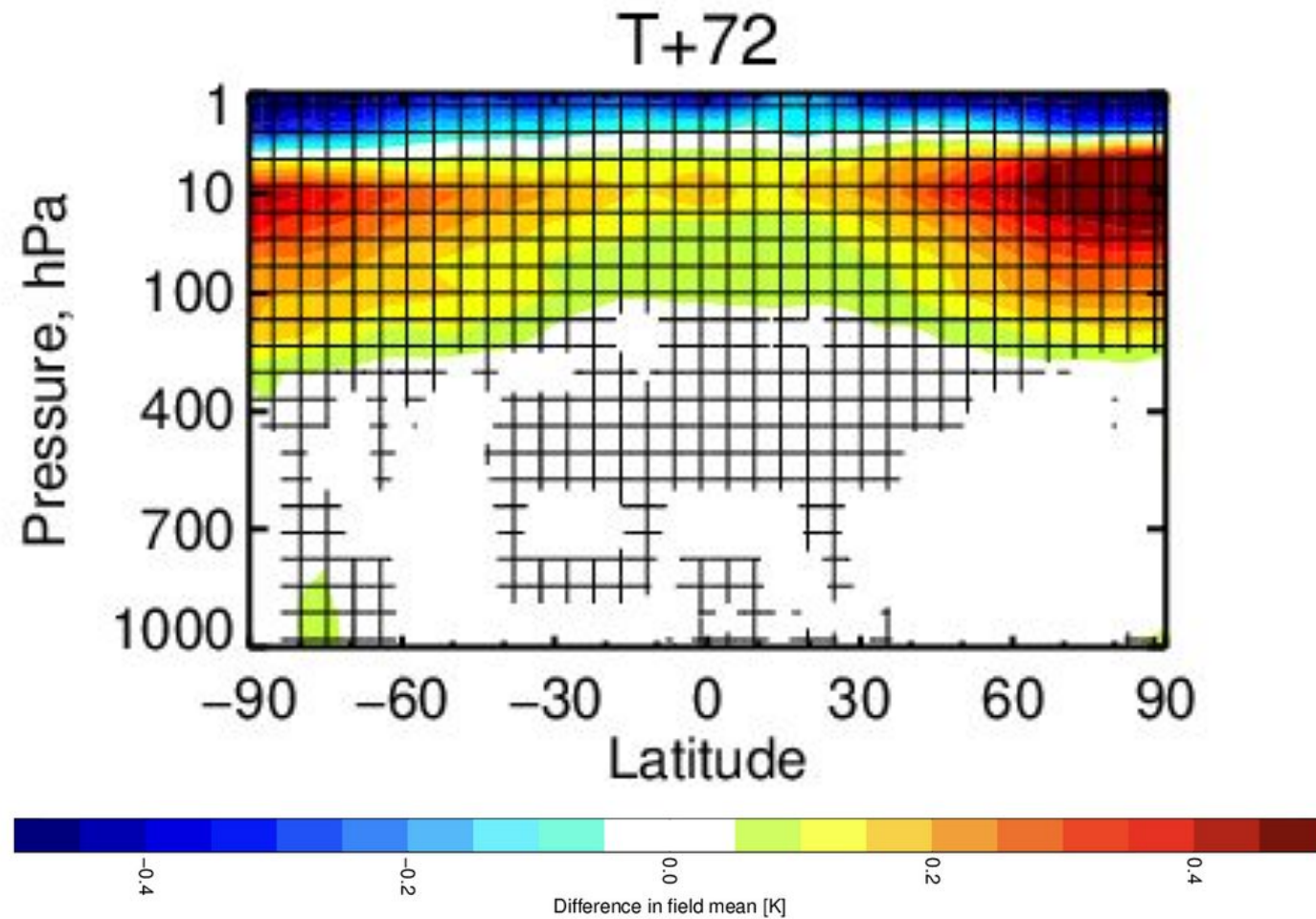
mean change in temperature

ROMEX - control



mean change in temperature

ROMEX no hydro - control



0.1% refrac coeff.

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

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
```

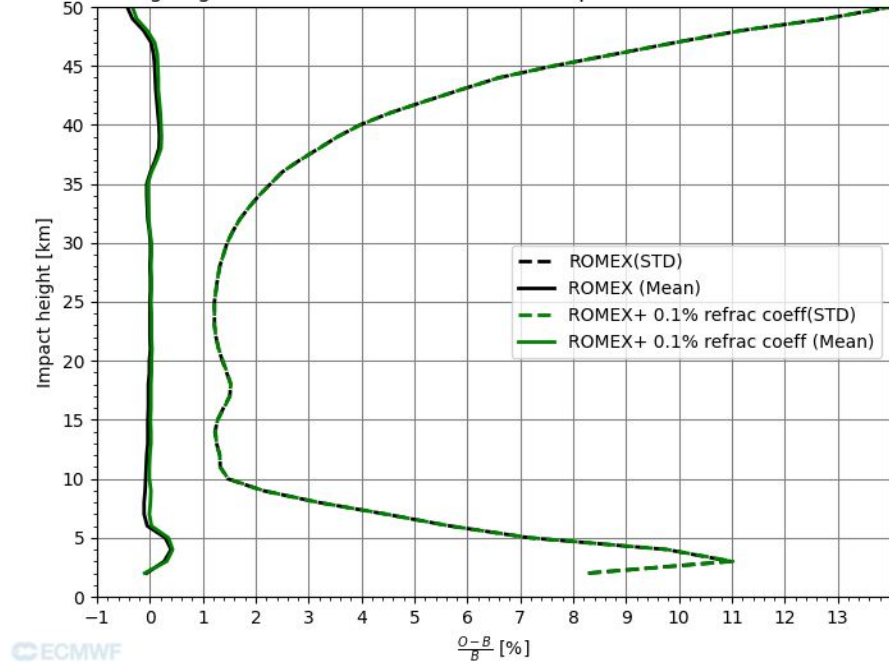
```
Z_NDRY = Z_AVAL*Z_PD/P_TEMP(I,J)
```


Normalised FG dep for Spire data

testing 0.1% refrac coeff

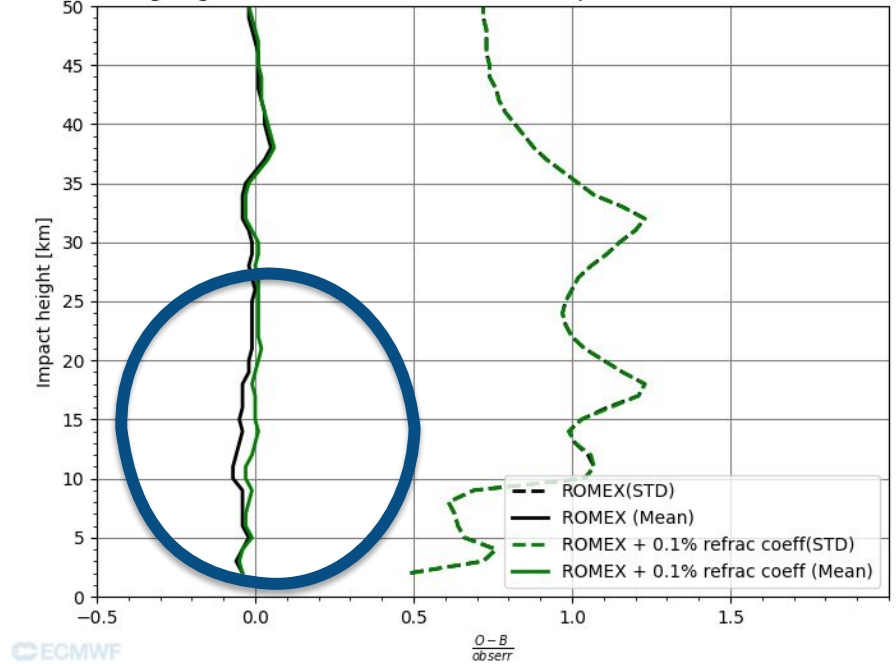
by
FG

Global Bending Angle Norm. Innovation Statistics for spire from 2022091000 to 2022092012



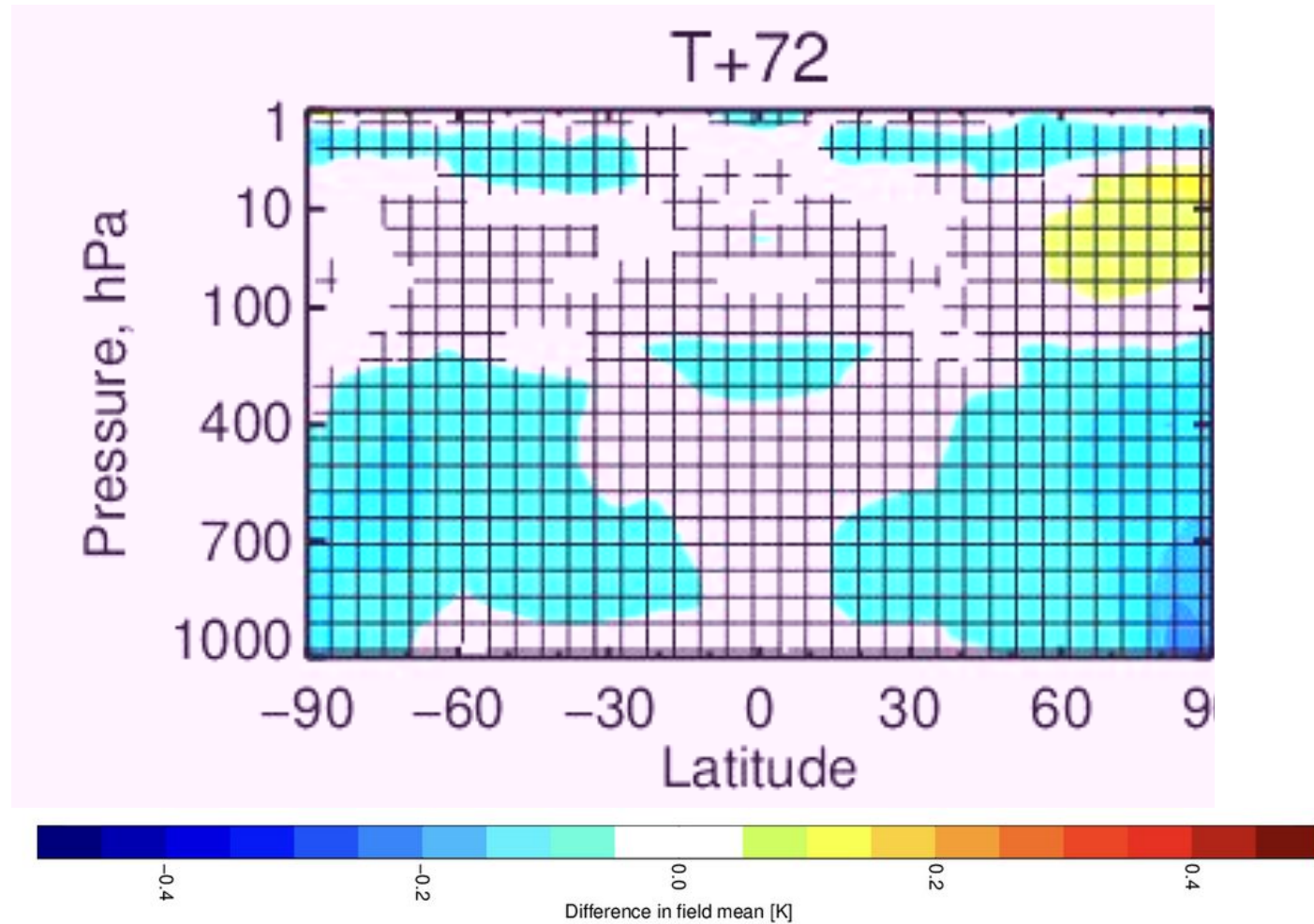
by obs error

Global Bending Angle Norm. Innovation Statistics for spire from 2022091000 to 2022092012



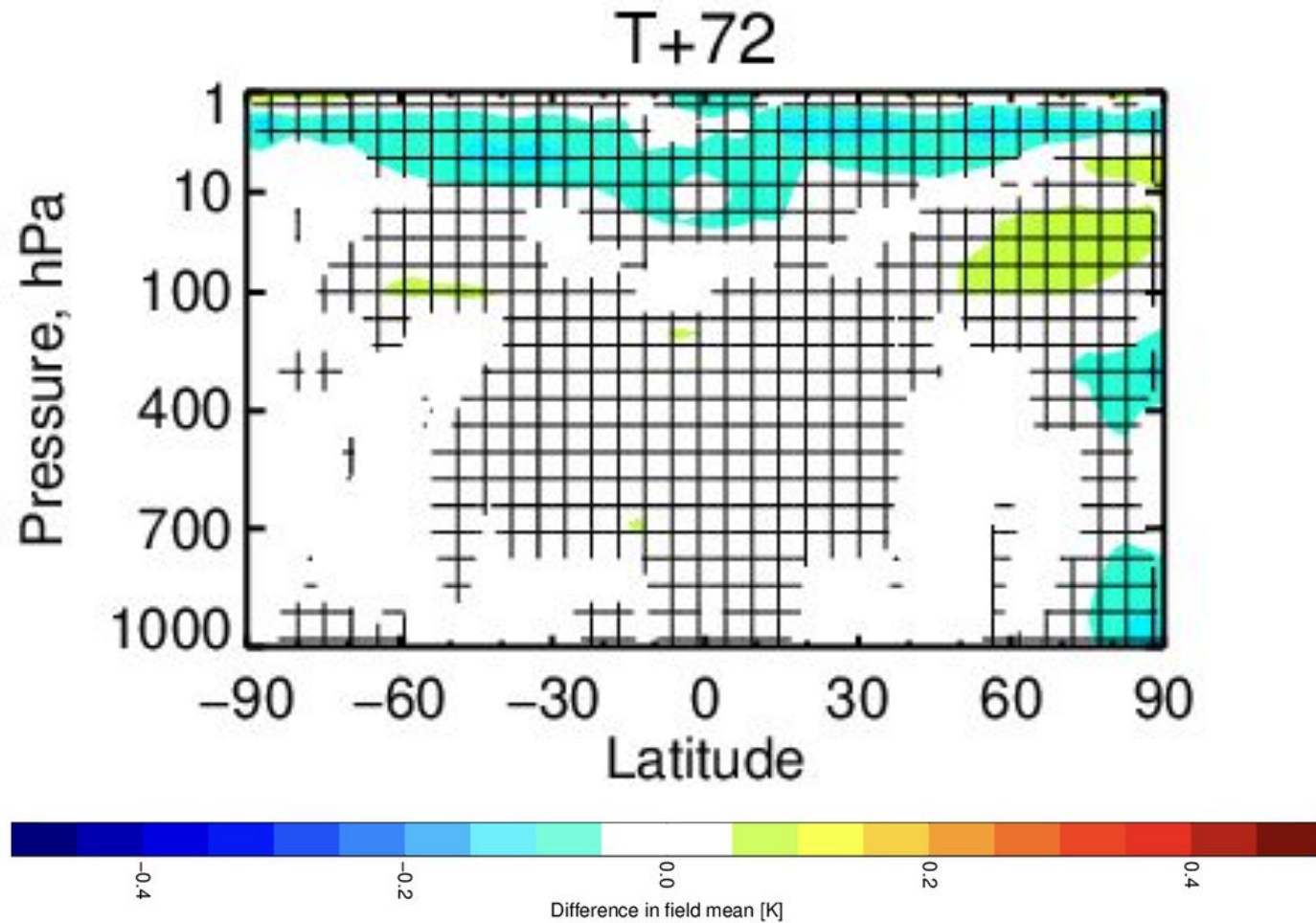
mean change in temperature

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)

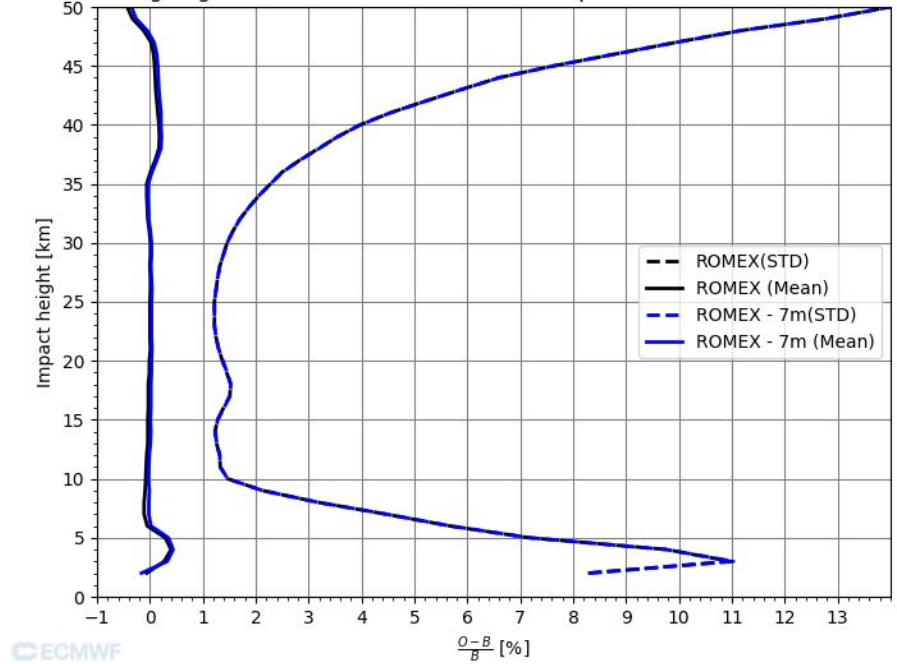
Height of 7m is ~0.1% scale height of refractivity, being ~7km

Normalised FG dep for Spire data

testing -7m

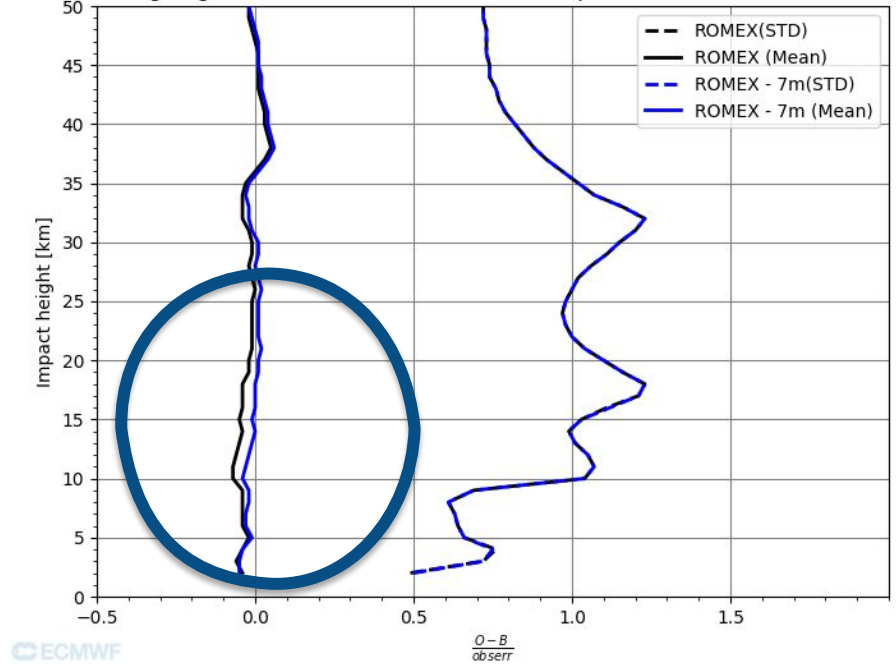
by
FG

Global Bending Angle Norm. Innovation Statistics for spire from 2022091000 to 2022092012



by obs error

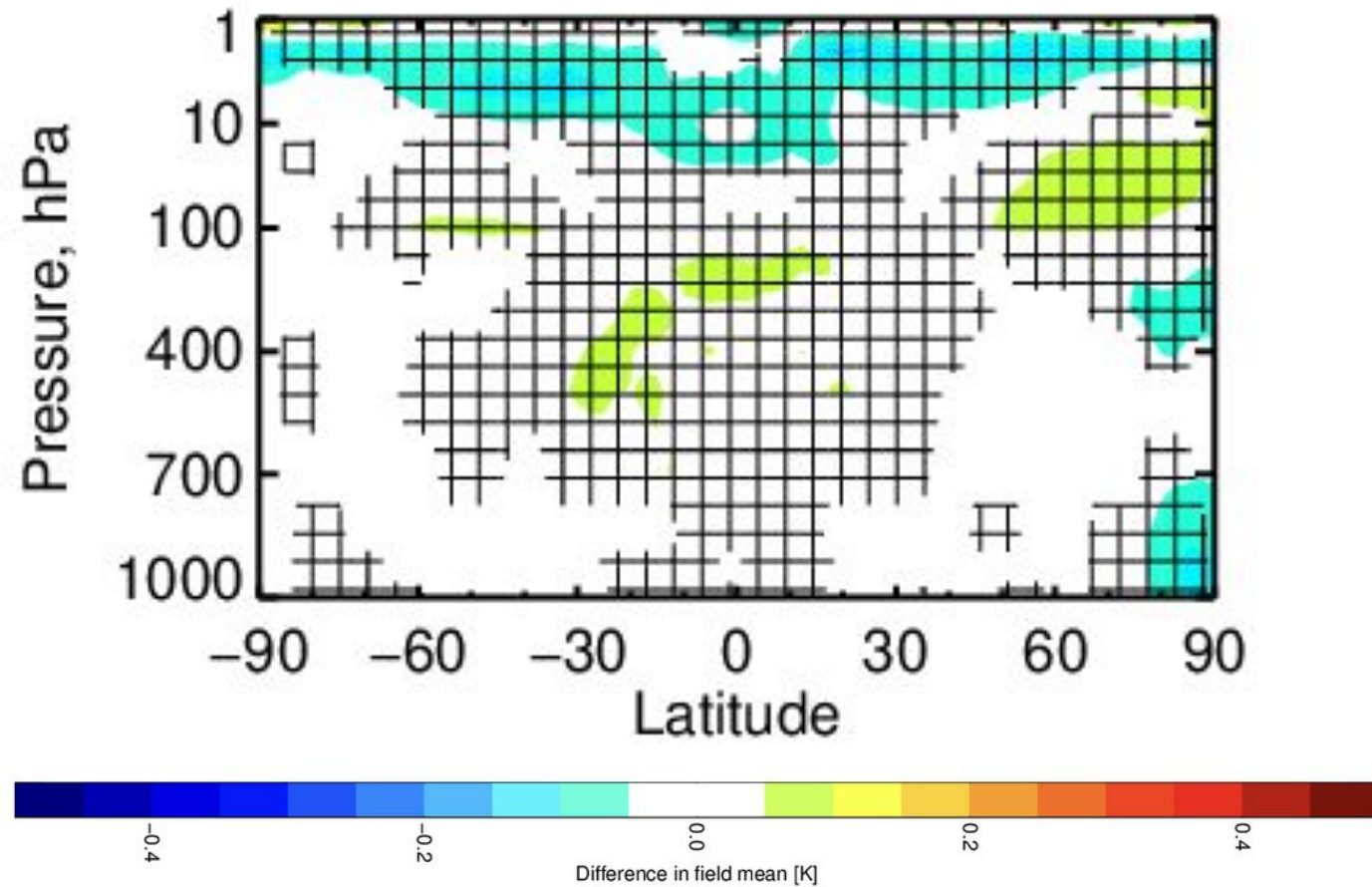
Global Bending Angle Norm. Innovation Statistics for spire from 2022091000 to 2022092012



mean change in temperature

- 7m - control

T+72

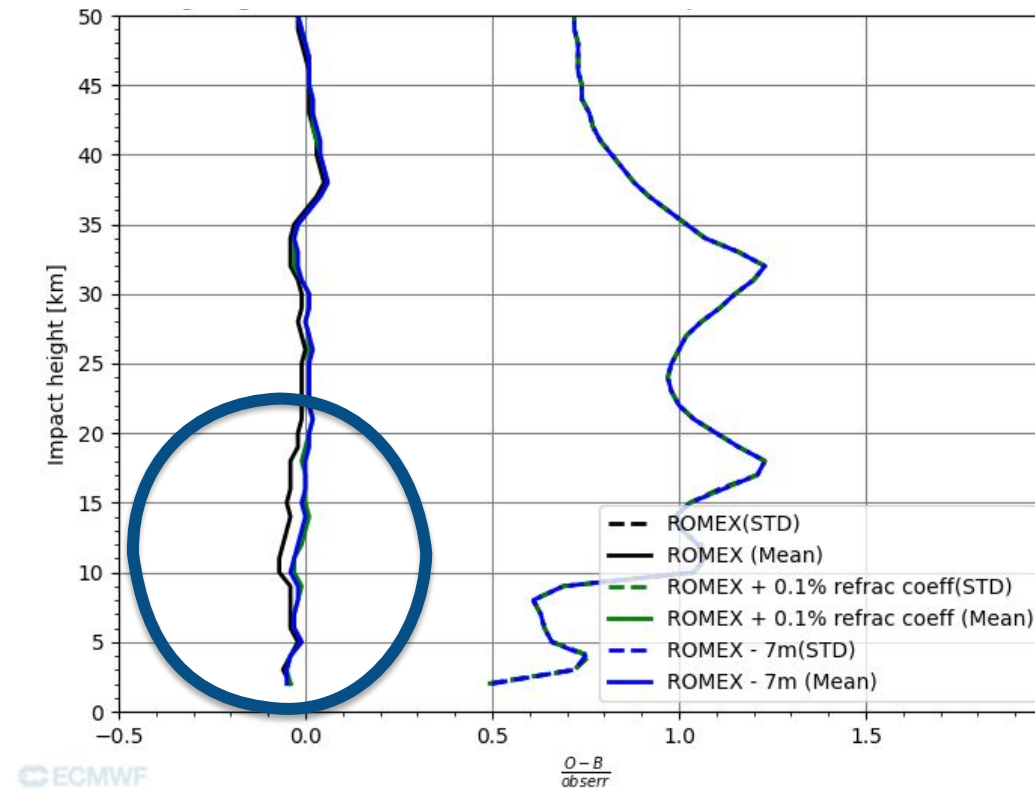


normalised FG dep for Spire data

(by obs
error)

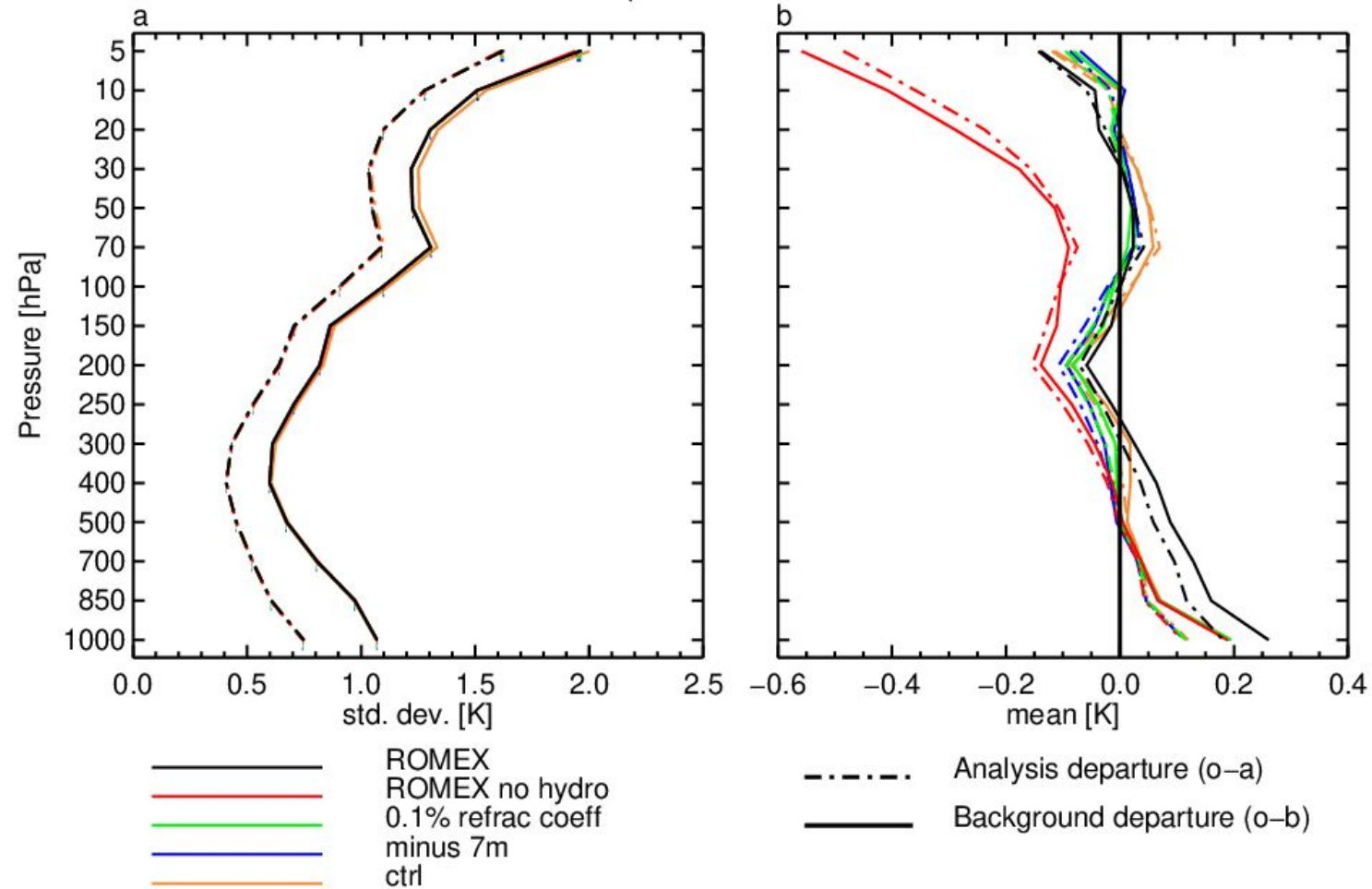
testing 0.1 % refrac coefficient in FO

testing subtracting 7m in calculating geometric height in FO



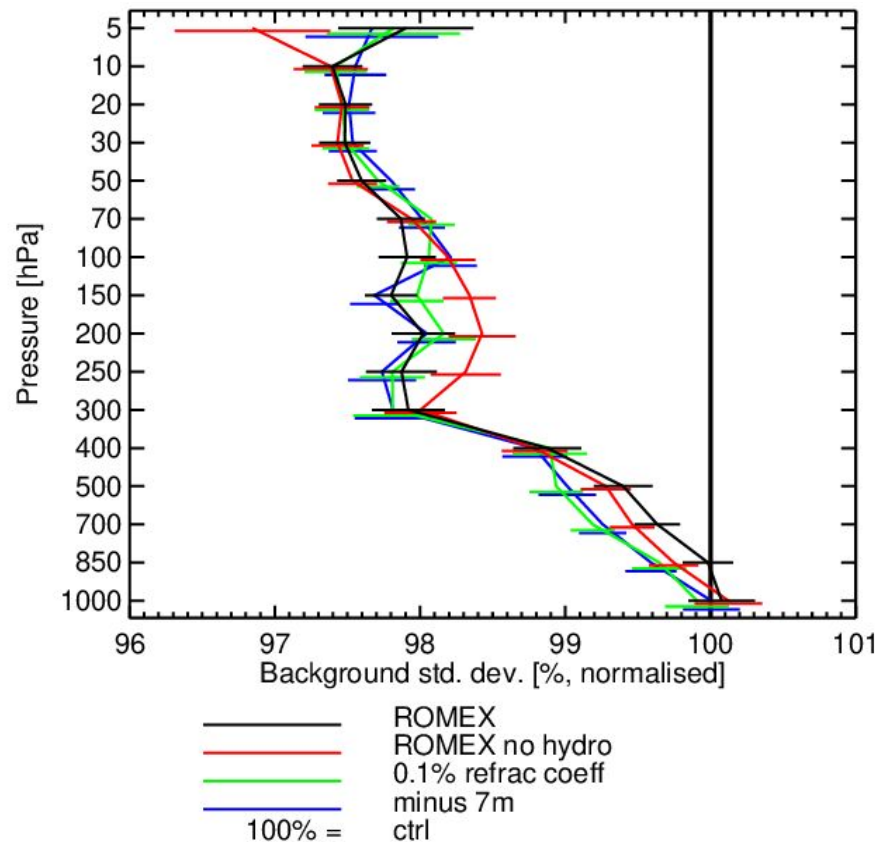
Fit to radiosonde temperature observations

Instrument(s): TEMP – T Area(s): N.Hemis S.Hemis Tropics
From 00Z 10-Sep-2022 to 12Z 30-Nov-2022

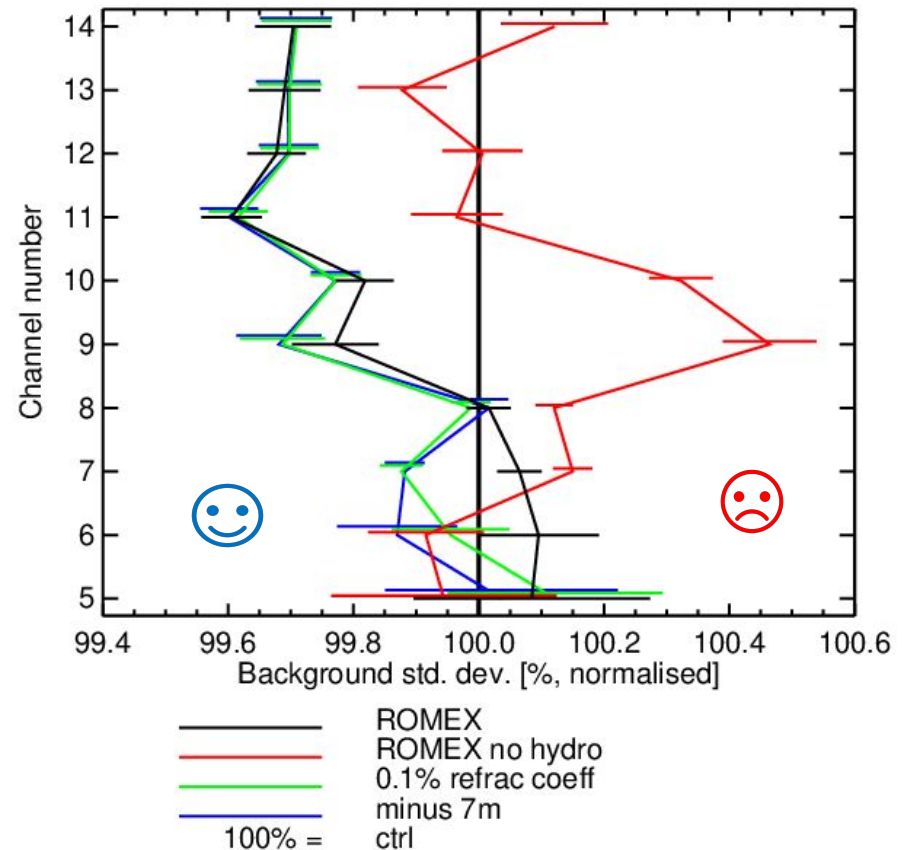


Impact on short-range forecasts (12h): Change in std dev in First Guess departures (globally)

Radiosonde temperature

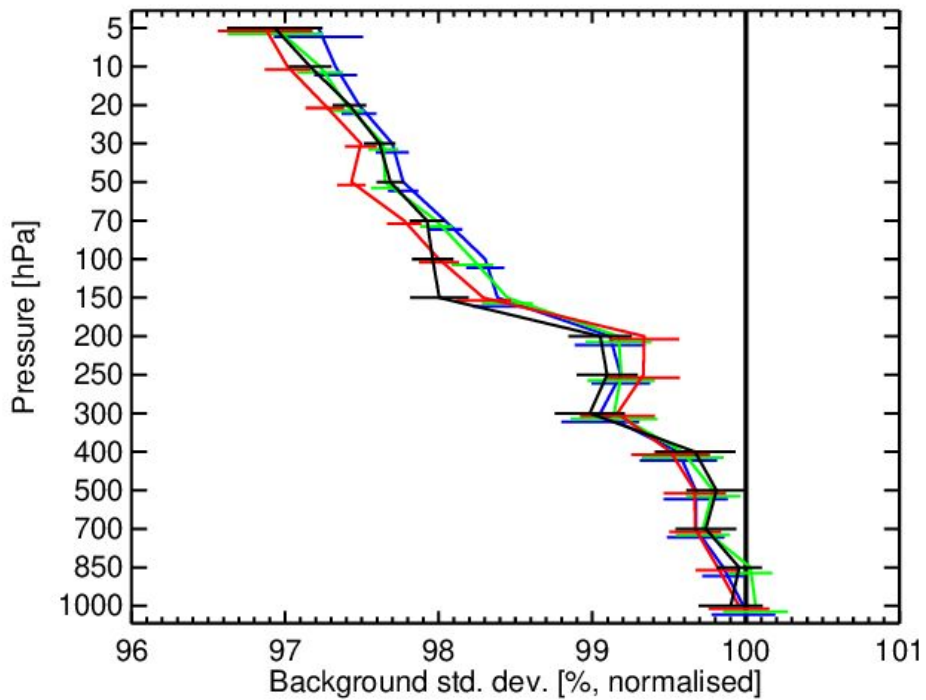


AMSU-A



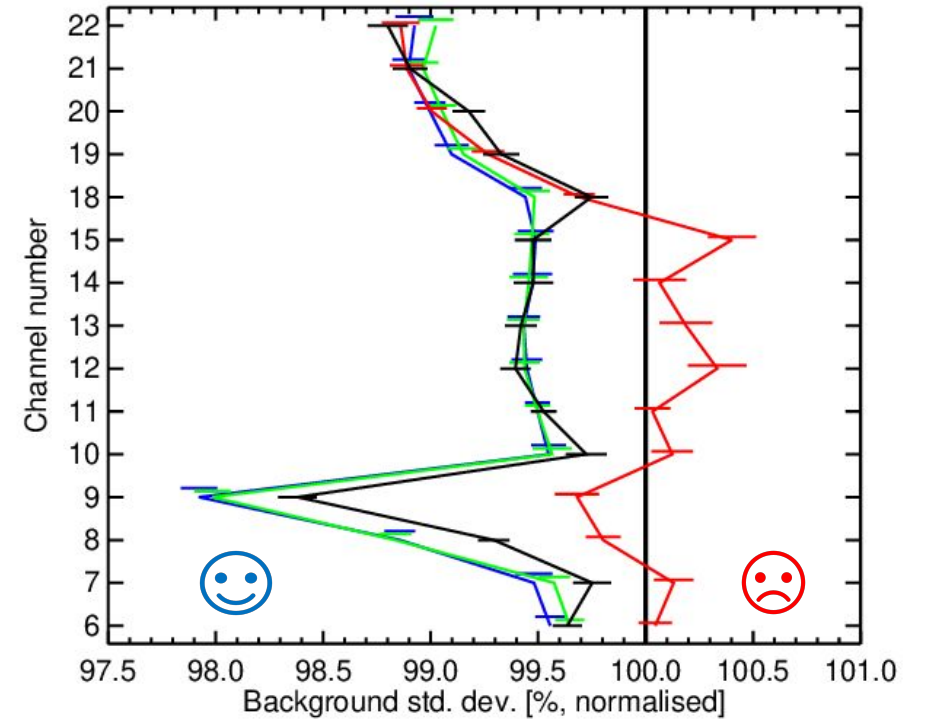
Impact on short-range forecasts (12h): Change in std dev in First Guess departures (globally)

Wind observations



- ROMEX
- ROMEX no hydro
- 0.1% refrac coeff
- minus 7m
- 100% = ctrl

ATMS

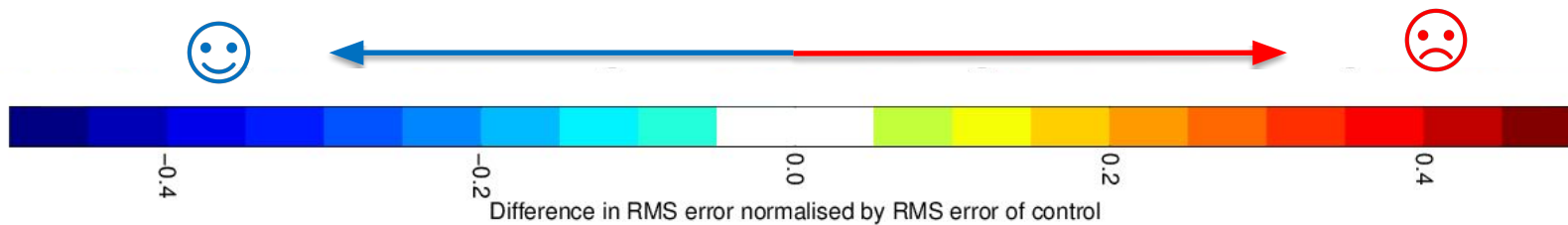
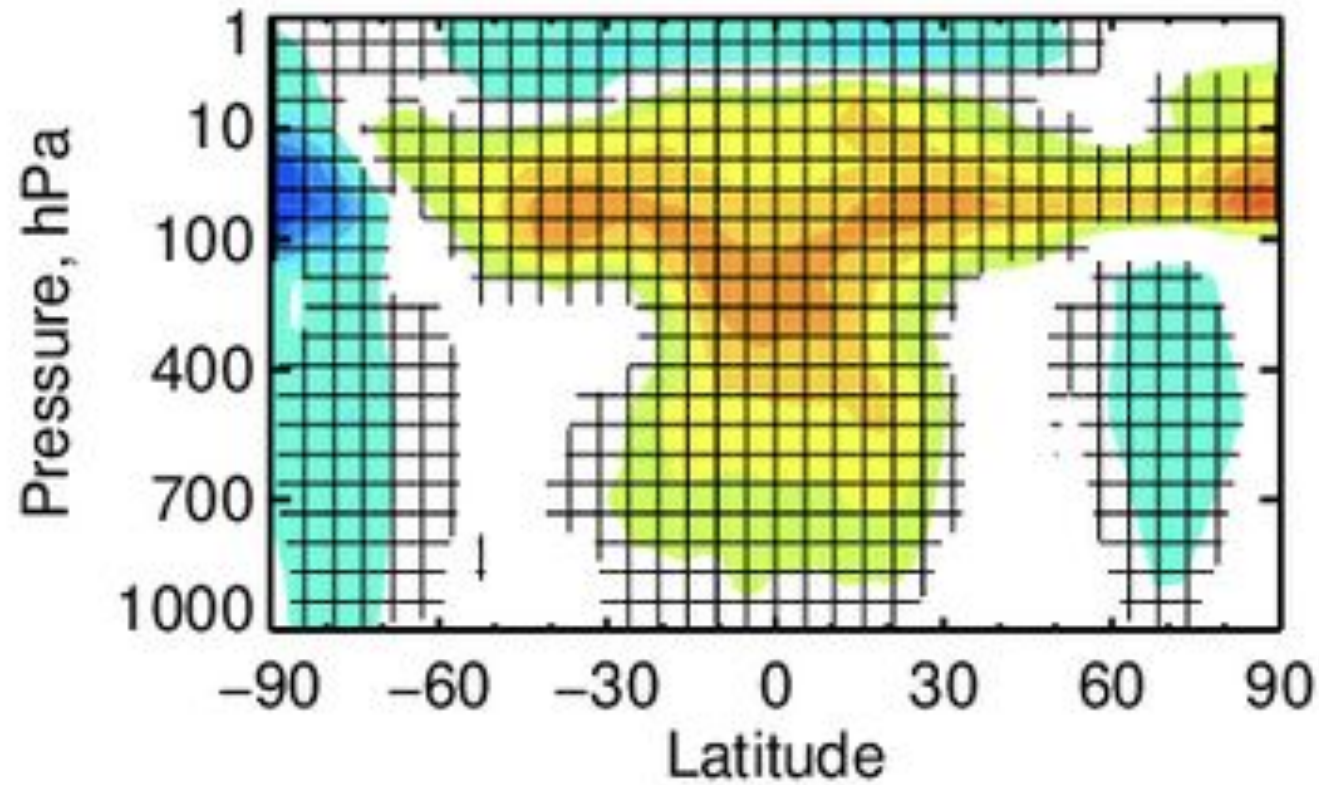


- ROMEX
- ROMEX no hydro
- 0.1% refrac coeff
- minus 7m
- 100% = ctrl

Increase in RMSE for Geopotential

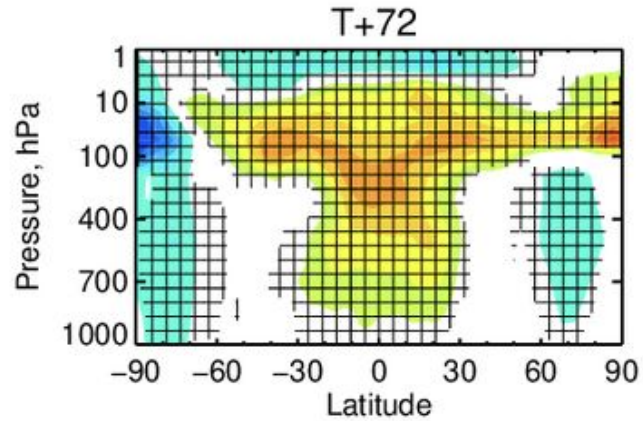
ROMEX - control

T+72

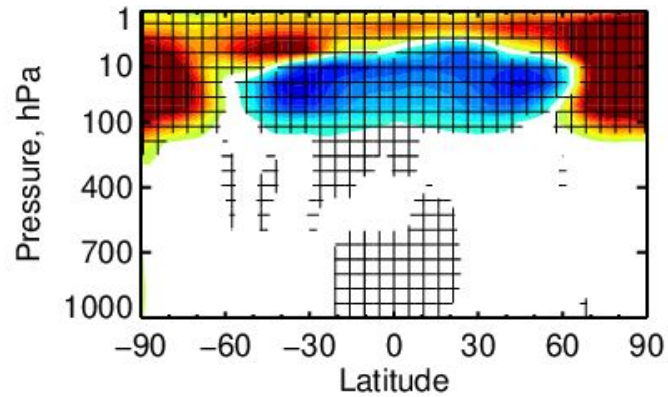


Change in RMSE for Geopotential

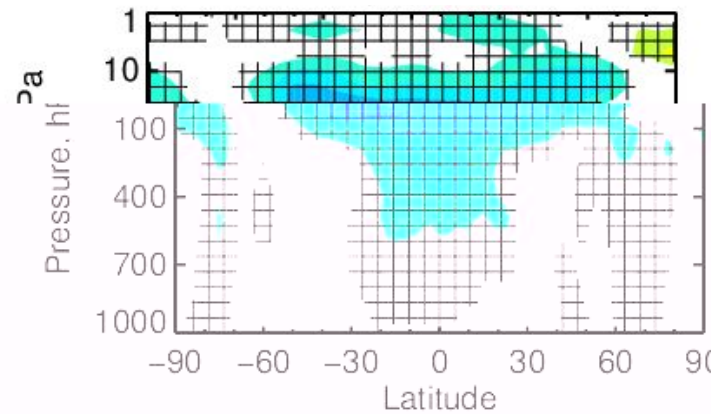
ROMEX - control



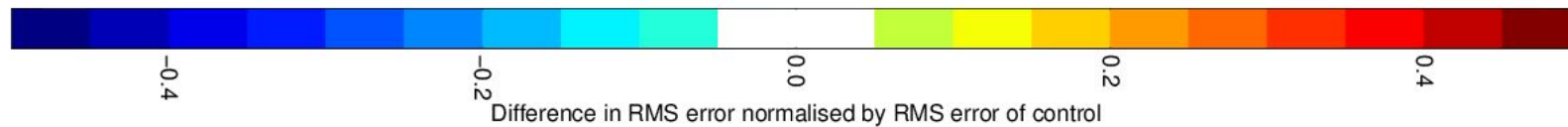
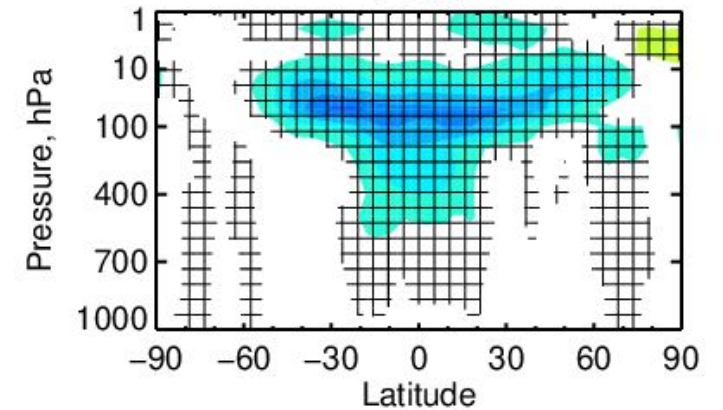
ROMEX no hydro - control



0.1% refrac coeff - control



Minus 7m - control



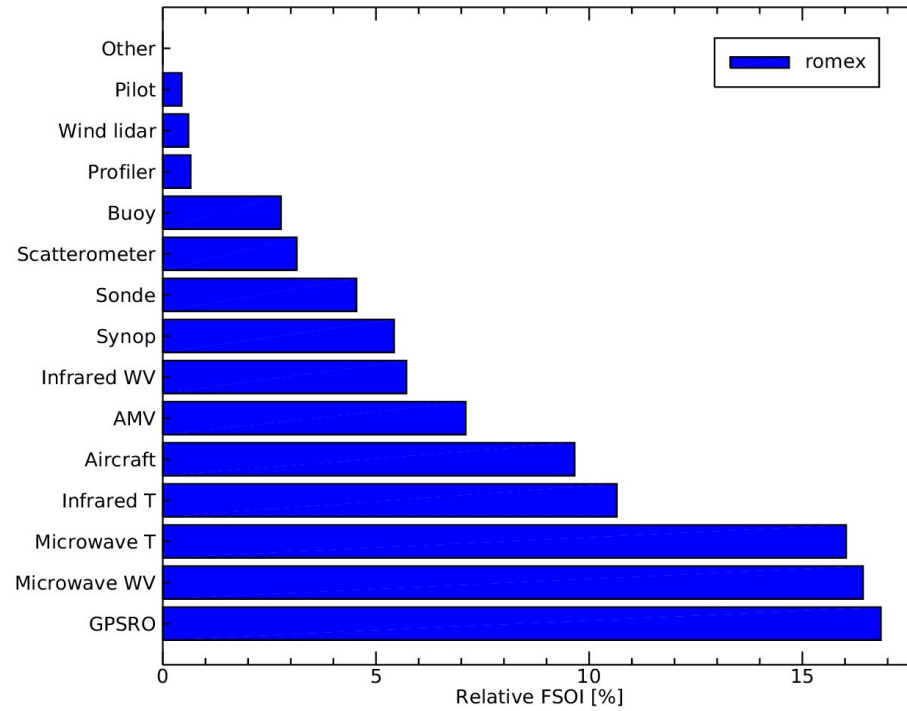
Summary Sensitivity Studies

- 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 be 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?

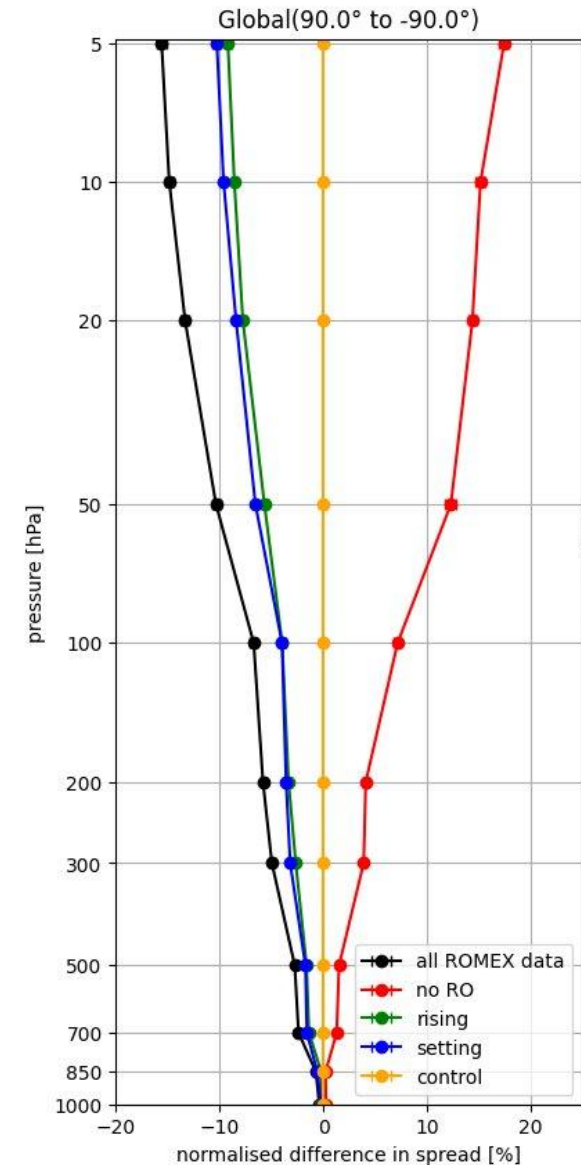
Don't forget...

FSOI

10-Sep-2022 to 29-Nov-2022

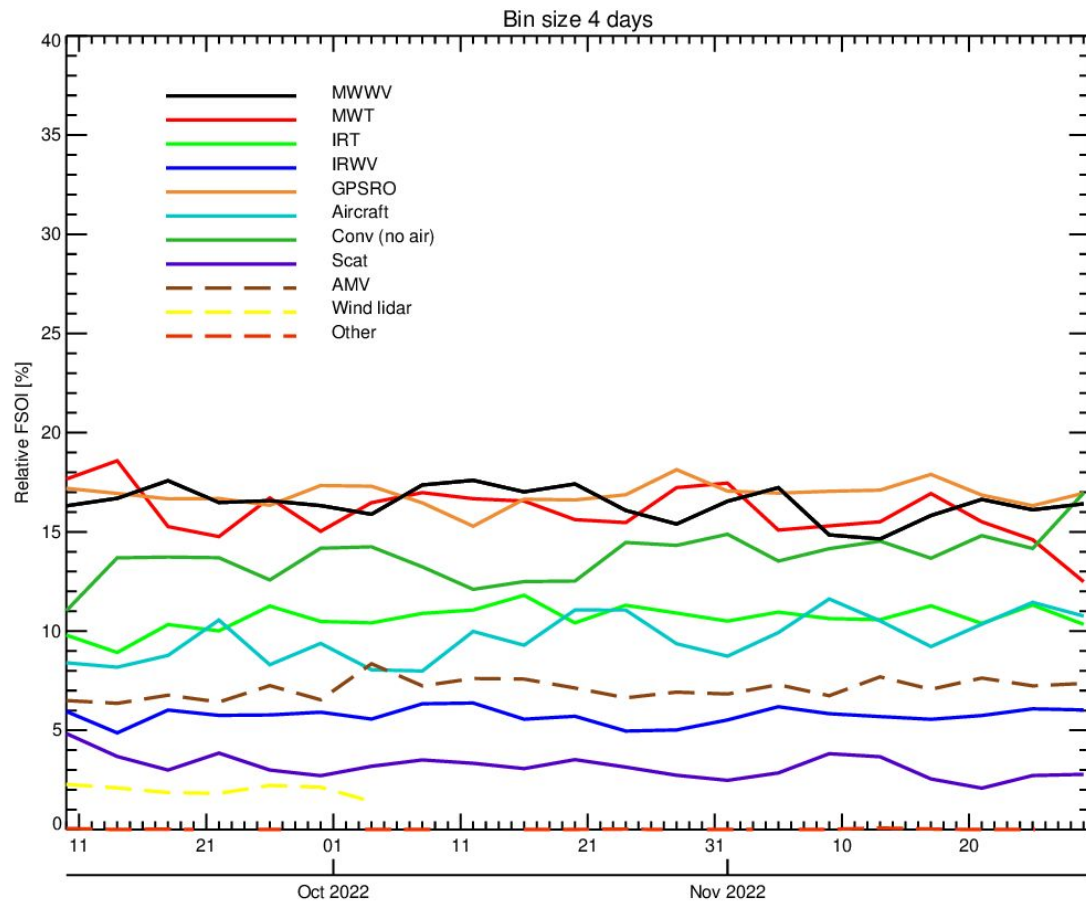


EDA for temperature, T+12h

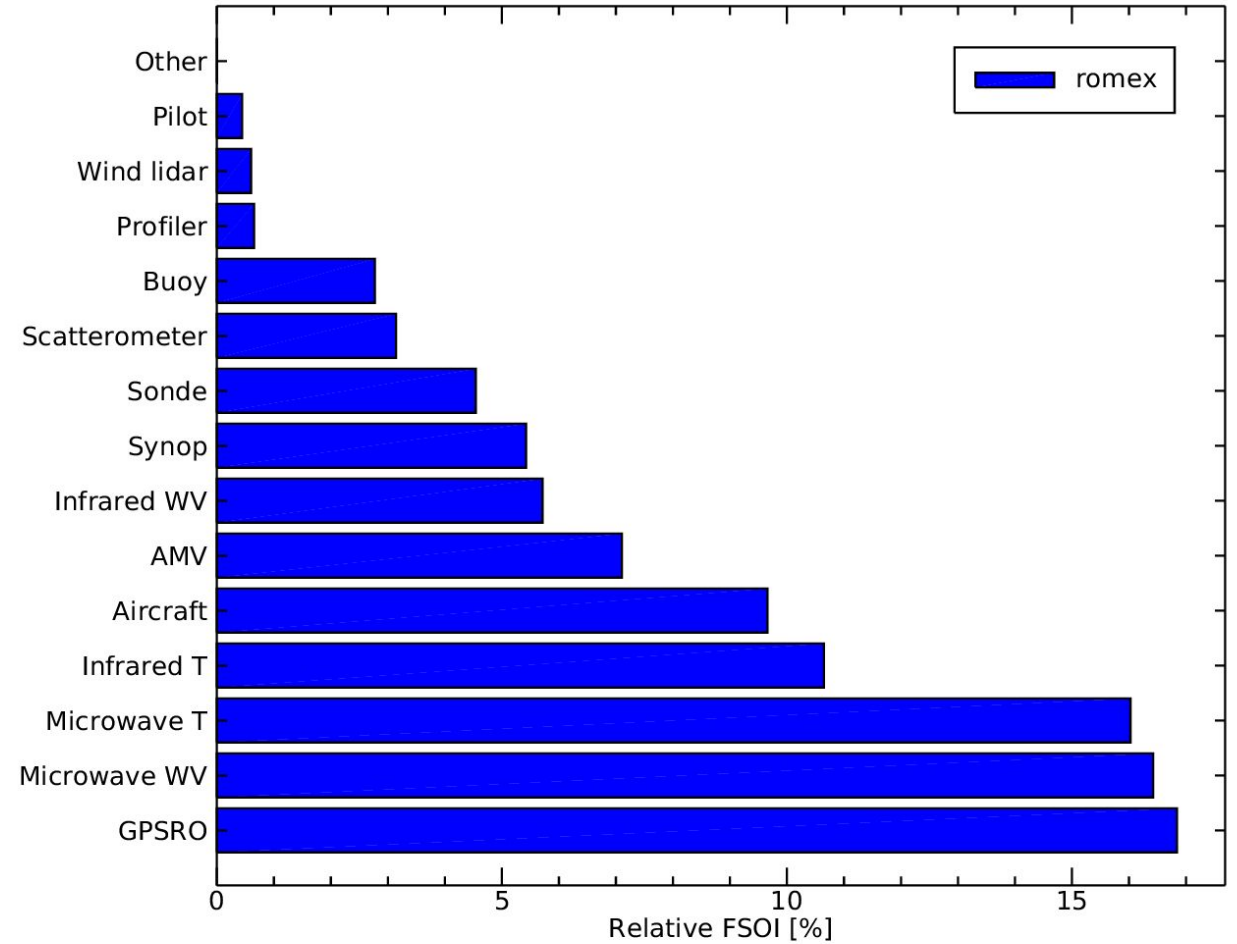


Backup

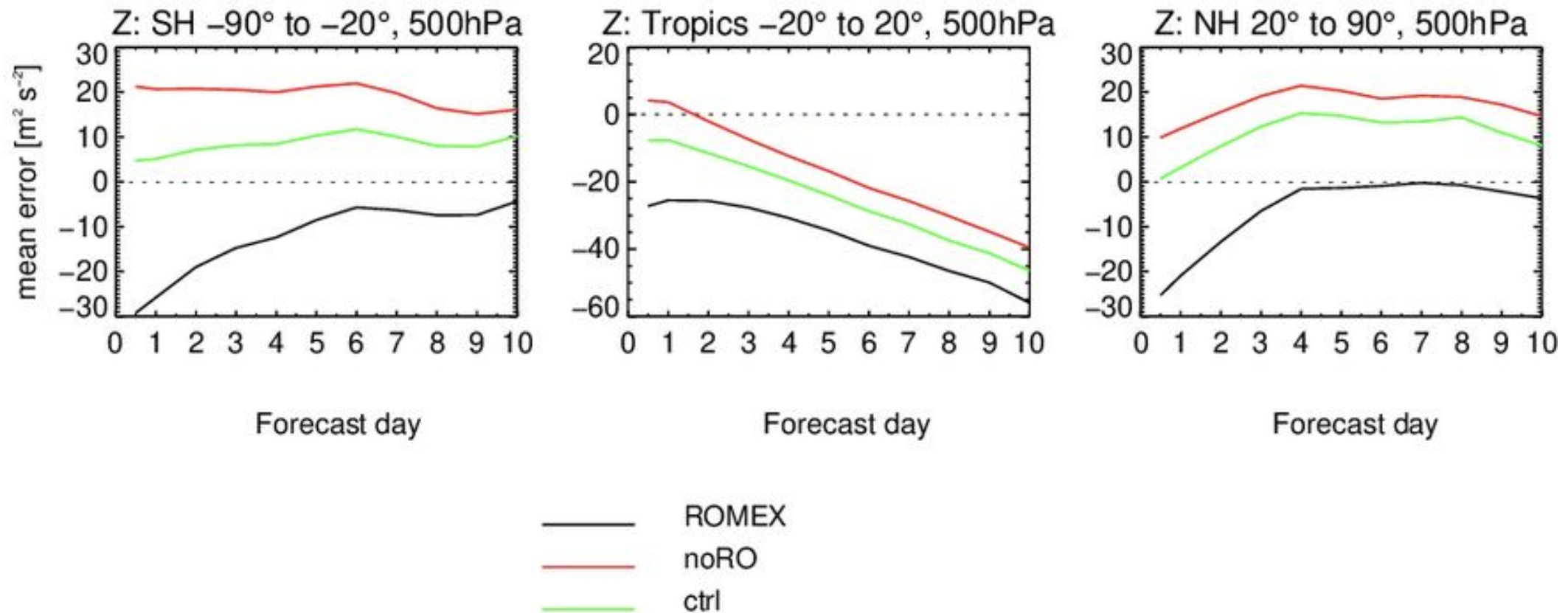
FSOI



10-Sep-2022 to 29-Nov-2022



Change in mean error for geopotential@500hPa



From Rick Anthes collection about refractivity calculation

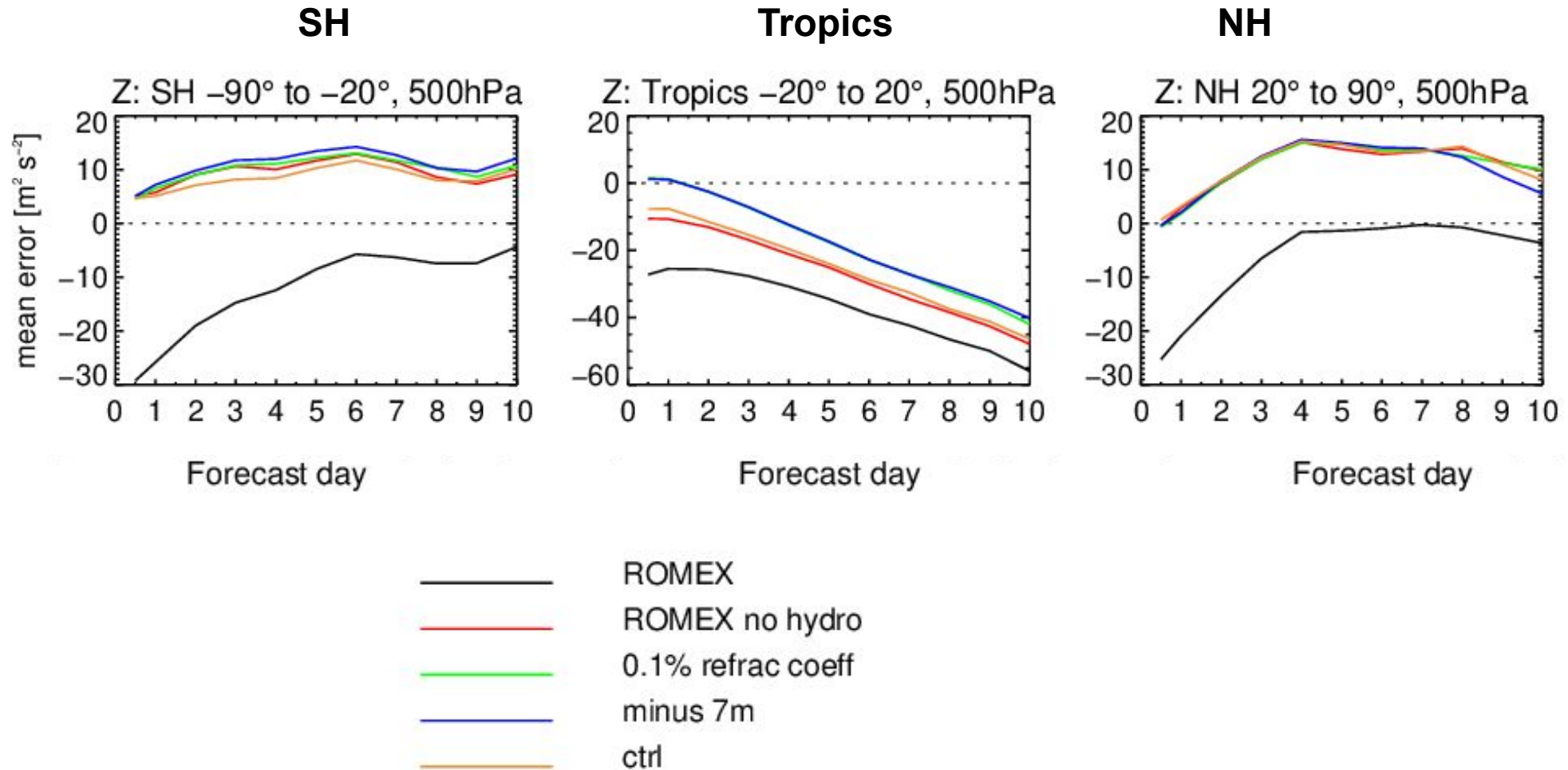
Table 2 Source	k_1	k_2	k_3	Comments
Cucurull 2010 Exp. PREXPB	77.6890	71.2952	3.75463	Basis for NCEP GSI/GSF model system. Rueger 2002
Xuanli Li 5-12-24 GFS operational	77.6890	71.2952	3.75463	Same as NCEP
M. Murphy (5-11-24) GMAO V1	77.6890	71.2952	3.75463	Same as NCEP
Taiwan CWA	77.6890	71.2952	3.75463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

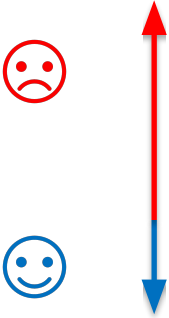
- $$N = k_1 P_d / T + k_2 e / T + k_3 e / T^2$$

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

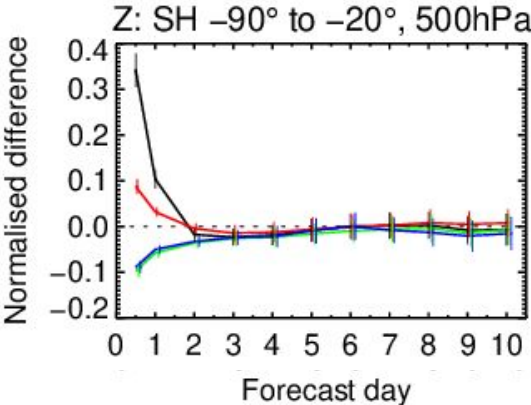
Change in mean error for geopotential@500hPa



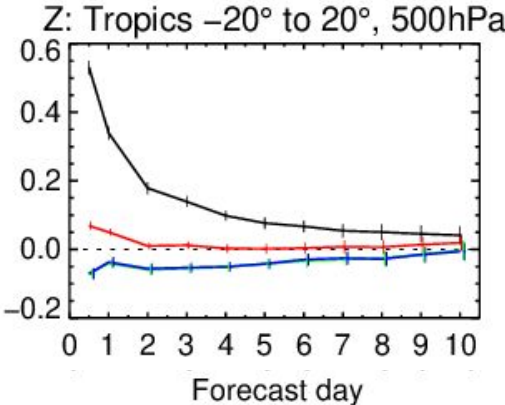
Change in RMSE for Geopotential forecast error @ 500hPa



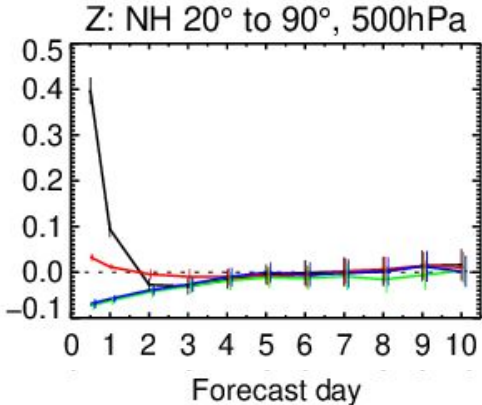
SH



Tropics



NH



- ROMEX – ctrl
- ROMEX no hydro – ctrl
- 0.1% refrac coeff – ctrl
- minus 7m – ctrl