Quantification of Structural Uncertainty in Climate Data Records from GPS RO

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Outline

- Background
- Centers and their processing
- Data and study setup
- Method
- Results
- Conclusions and outlook

Background

- **Aim:** Quantifying the structural uncertainty of RO data provided by different RO processing centers

- **Background:**
  - 1st round study by Ho et al. (JGR, 2009)
  - Intercomparison of refractivity climatologies
  - CHAMP 2002–2006
  - 4 centers JPL, GFZ, UCAR, WEGC
  - Structural uncertainties amongst climatologies of different RO processing centers are <0.03% per 5years for refractivity trends in large scale means

Data and Study Setup

- 2nd round intercomparison studies
- Profile to profile comparison (PPC) provided by RO processing centers (study by S-P. Ho, JGR subm. Feb 2012)
- Intercomparison of zonal monthly mean climatologies (MMCs)
- Results of MMC intercomparison presented at OPAC 2010, Graz and at 5th F3C-ICGPSRO 2011, Taiwan
- Helped to improve data at different centers
- Reprocessed data were provided

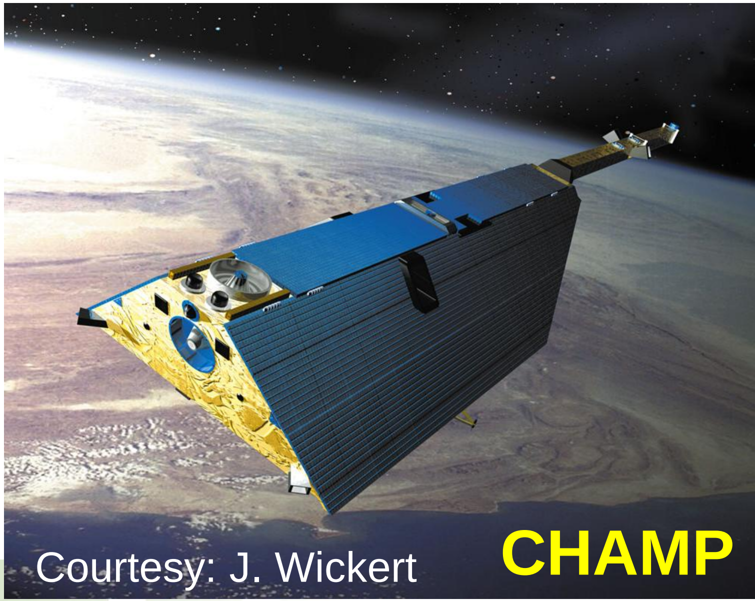
Centers and Processing

Processing Center	Data version	Processing Steps [a]
DMI Copenhagen, DK	OCC_20.6.688, FM_2.1 (UCAR/CDAAC 2009.2650)	UCAR phase & orbit data Geometrics optics (GO), CanonTransf (CT)<25 km Optimization of α with MSIS-E90 (>40 km)
EUM Darmstadt, D	YAROS 0.1(Beta) – ROTrend_5.1_Prof (UCAR/CDAAC 2009.2650)	UCAR phase & orbit data GO Optimization of α with CIRA-MSISE
GFZ Potsdam, D	POCS ATM vers.006	Excess phase single differencing GO, Full Spectrum Inversion (FSI) <15 km Optimization with MSISE-90 (>40 km)
JPL Pasadena, CA, USA	v2fo_10Kp1N	Excess phase double differencing CT Exponential function fit of α at 40–50 km, extrapol.
UCAR Boulder, CO, USA	2009.2650	Excess phase single differencing GO, Full Spectrum Inversion in troposphere Optimization with NCAR climatology
WEGC Graz, A	OPSv5.4 (UCAR/CDAAC 2009.2650)	UCAR phase & orbit data GO Statistical optimization >30 km with ECMWF forecasts & MSIS-E90 above

[a] All centers: Ionospheric correction of bending angles and dry air retrieval but different smoothing routines and quality control

Data and Study Setup

- **CHAMP** record September 2001 to September 2008
- Resolution: 5-degree zonal means, monthly means
- **Latitude zones:** Tropics (TRO) 20°N–20°S
  Northern/Southern mid-latitudes (NML/SML): 20°N/S–50°N/S
  Northern/Southern high-latitudes (NHL/SHL): 50°N/S–90°N/S
- **Altitude range:** 8–30 km (200 m)
- **Altitude layers:** 8–12 km (Upper Troposphere UT)
  12–18 km (Tropopause TP)
  18–25 km (Lower Stratosphere LS)
  25–30 km
- Focus region: Tropical UTLS
- **Parameters**[a]**:** Bending angle $\alpha(z_a)$
  Refractivity $N(z)$
  Dry pressure $p_d(z)$,
  Dry geop. height $Z_d(z_p)$
  Dry temperature $T_d(z)$

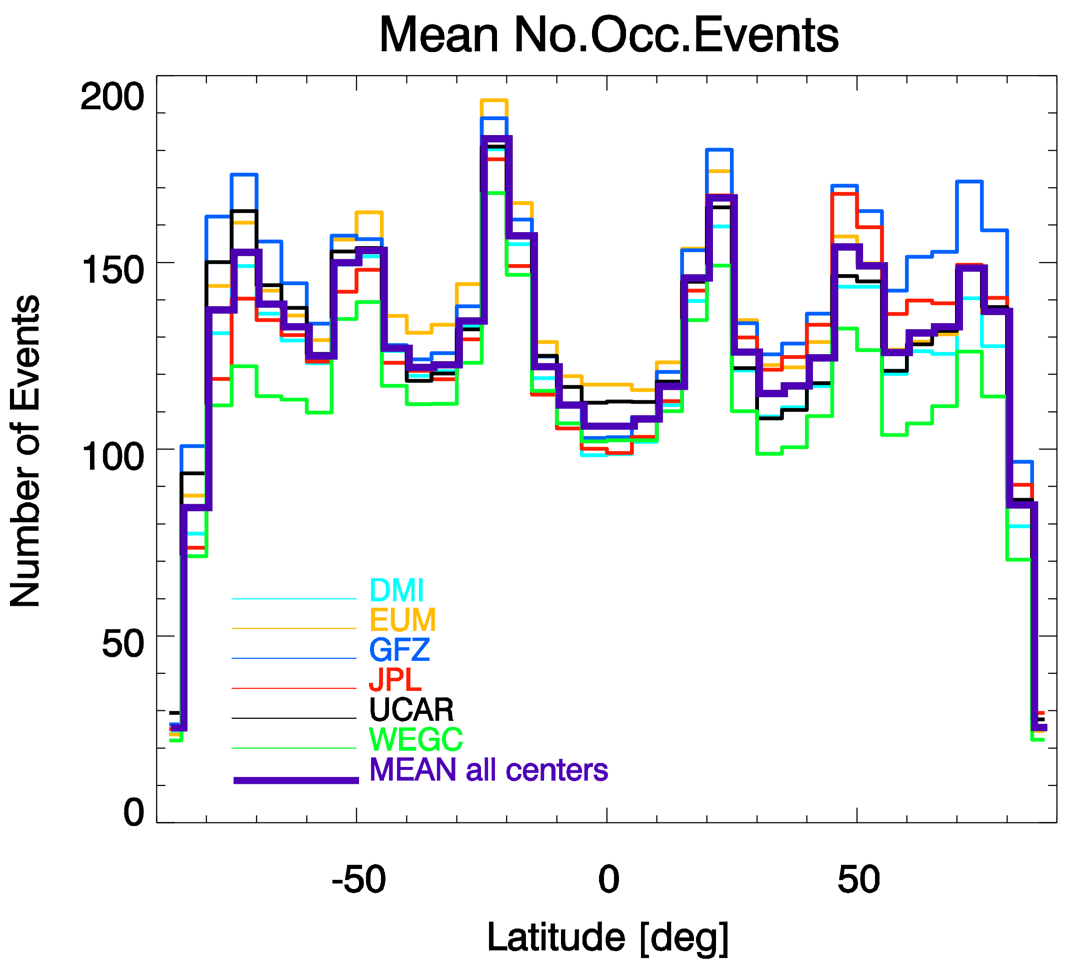


[a] msl altitude z, impact altitude z_a
(z_a = impact parameter – radius of curvature – geoid undulation),
pressure altitude $z_p(p)[m]=(7000\ m) \times \ln(1013.25\ hPa/p[hPa])$

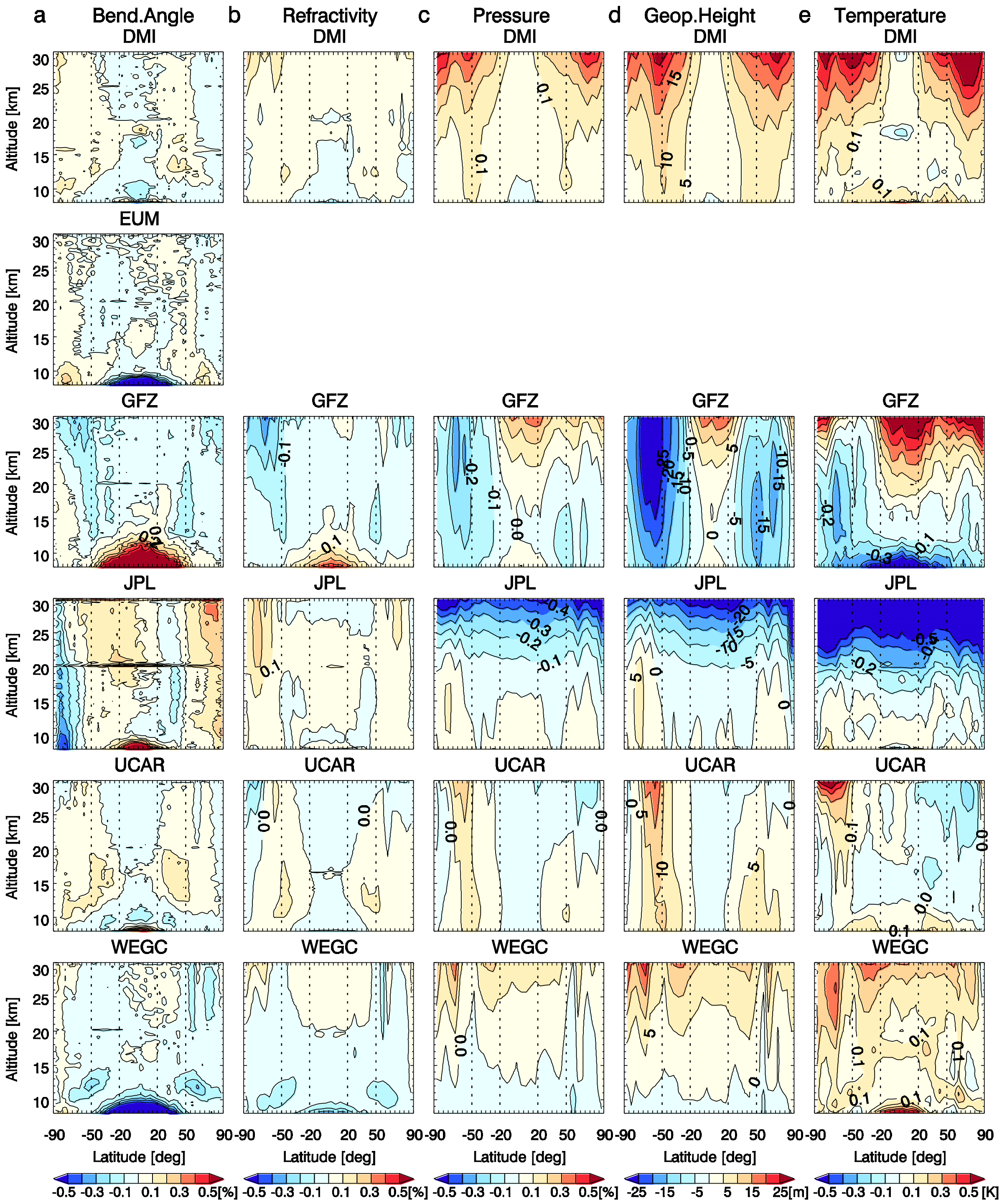
Method

- MMCs based on provided profiles
- Sampling error estimation based on ERA-Interim for N, p_d, Z_d, T_d
- Subtraction of sampling error: “de-sampled” 5-deg MMCs
- MMCs and de-sampled MMCs
- Mean difference of each center to the all-center mean
- Anomaly time series – mean annual cycle removed
- Anomaly difference time series – subtracting the all-center mean
  absolute anomaly difference for *Z* and *T* (anomaly – all-center mean)
  fractional anomaly difference for α, *N*, *p* (anomaly – all-center mean)/ all-center mean*100
  6 centers, 5 parameters, 36 lat-bands/110 altitude levels, 5 lat-zones/4 altitude layers
- Variability which is common to all data sets is removed,
  remaining deviations are due to different processing methods
- Trends of the anomaly difference time series
- All-center mean trend and standard deviation
- Structural uncertainty is estimated from
  the spread of anomaly difference trends and
  the standard deviation of the all-center mean trend

Number of Occultation Events



- No of events per 5-deg bin
- depends on quality control
- GFZ above average
- WEGC below average



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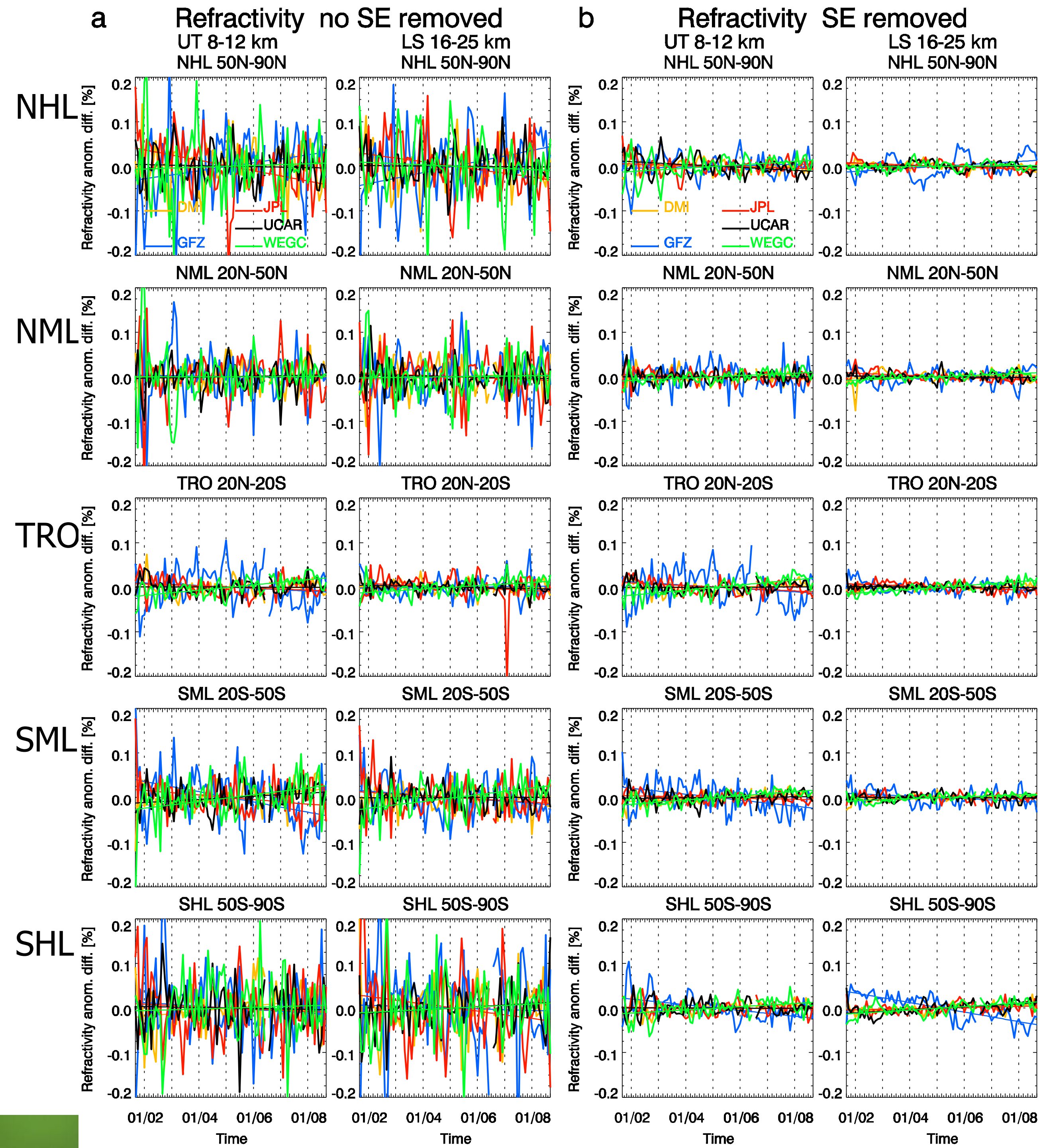
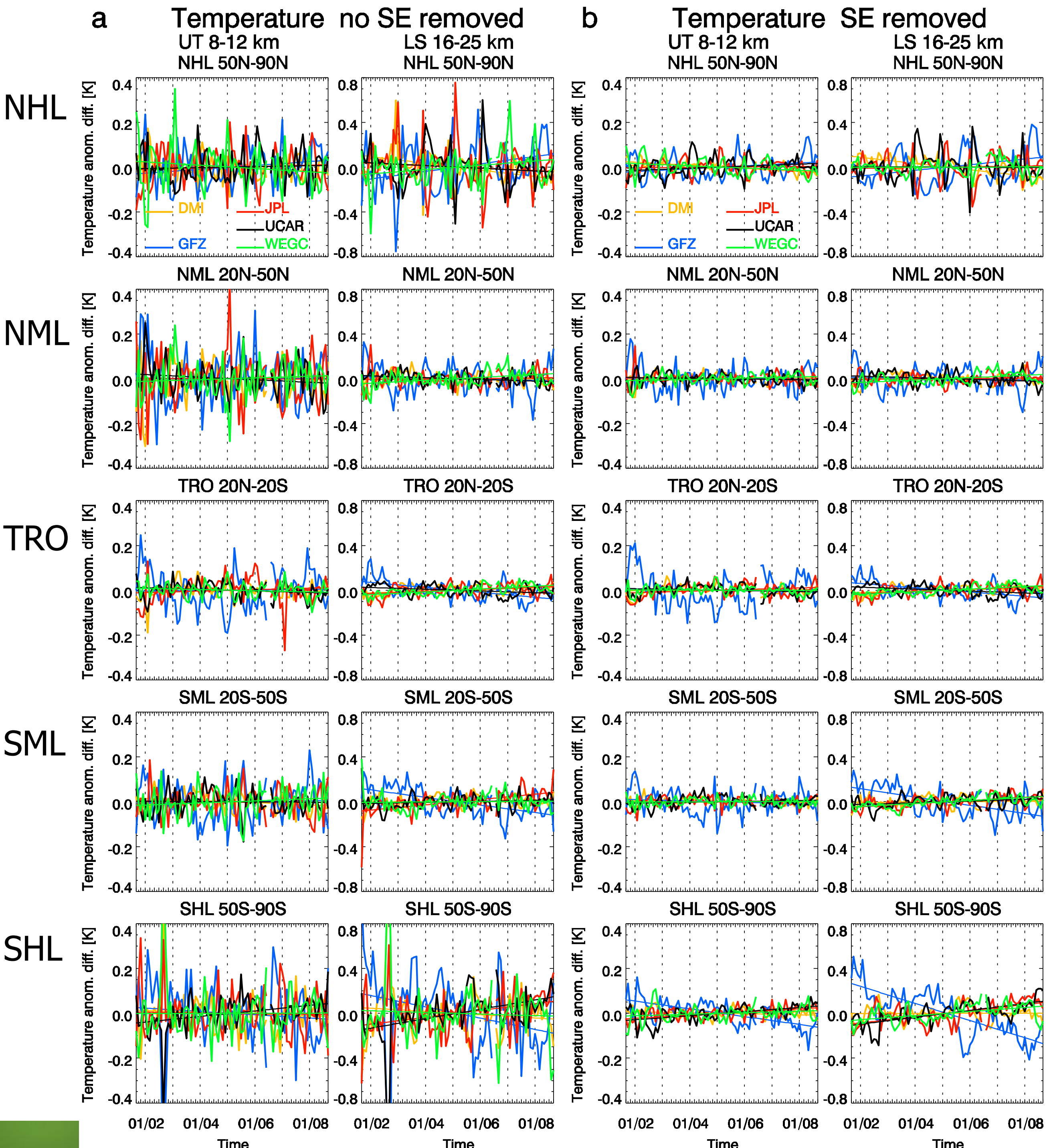
- **Mean difference of each center to the all-center mean** (top to bottom)
- for 09/2001 to 09/2008
- (a) bending angle and
- (b) refractivity
  ±0.1%
  up to ±0.3%
  above 20km at SHL
  below 10 km in tropics
- (c) pressure
  ±0.1% <20 km
  ±0.4% at 30 km
- (d) geopotential height
  5–10 m <20 km
  ~25 m at 30 km
- (e) temperature
  ±0.1 K <20 km
  ~0.5 K at 30 km

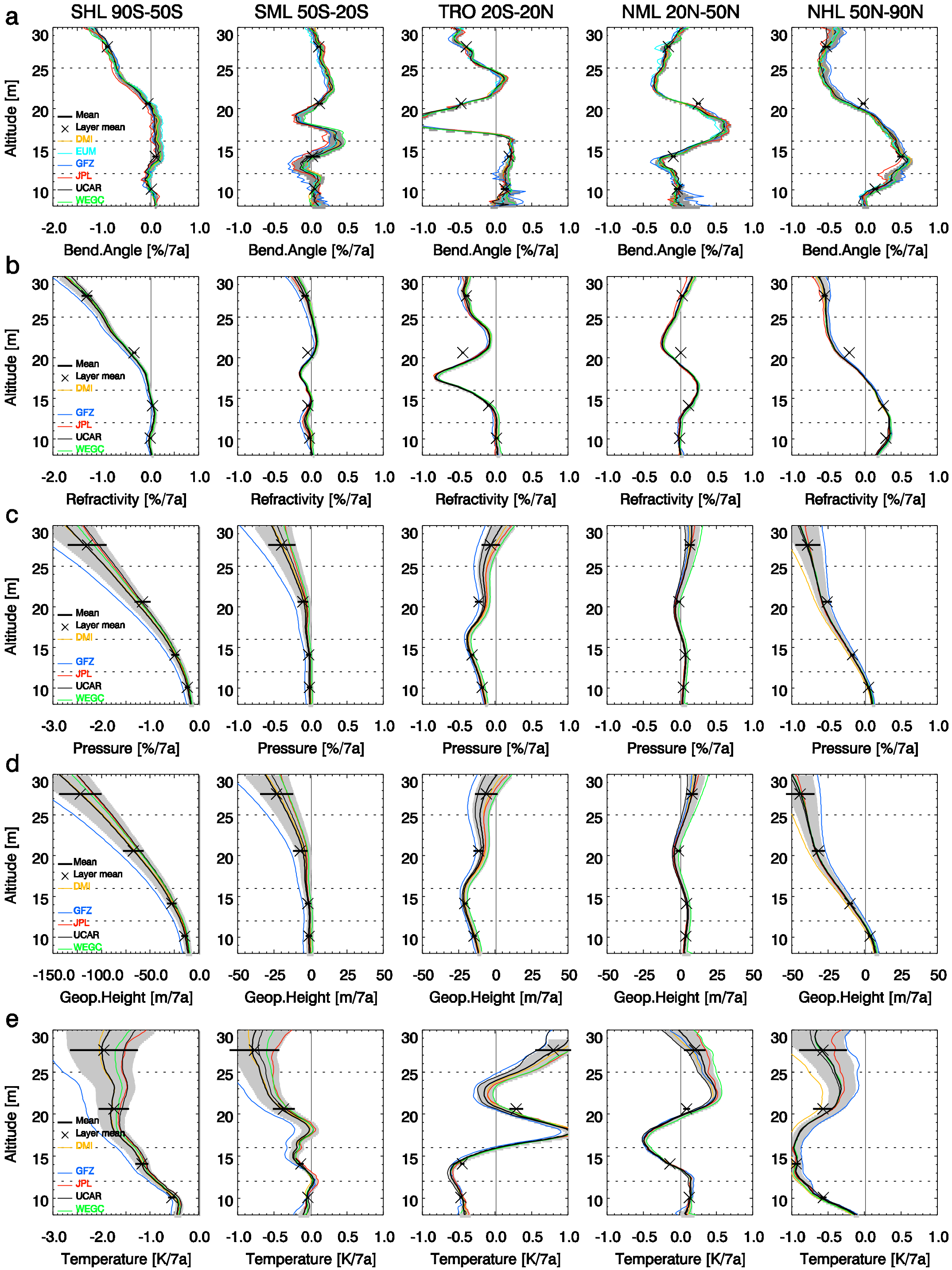


- **Anomaly difference time series & trends**
- **(a) refractivity**
- **(b) refractivity where sampling error was subtracted**
- UT (left) and LS (right) five zonal regions (top to bottom)

- Refractivity diff. trends: ±0.03% per 7 years larger at SHL



- **Anomaly difference time series & trends**
- **(a) temperature**
- **(b) temperature where sampling error was subtracted**
- UT (left) and LS (right) five zonal regions (top to bottom)
- Temperature diff.trends: UT: near zero ±0.1 K per 7 yrs at SHL LS: ±0.2 K per 7 yrs larger at SHL



- **All-center mean trends and standard deviation**
- for the period 09/2001 to 09/2008
- (a) bending angle
  (b) refractivity
  (c) pressure
  (d) geopotential height
  (e) temperature

- **Standard deviation:**
  bend.angle: <0.05%
  refractivity: <0.04%
  pressure: 0.03% to 0.05%
  0.2% to 0.4% at HL, LS
  geop.Height: 2 m to 3 m
  10 m to 20 m at HL, LS
  temperature: 0.02 K in UT
  0.1 K in LS
  0.2 K to 0.7 K >25 km

Structural uncertainty

- Mean standard deviation of trends per 7 years[a] at 8–25 km at 50S to 50N:
  0.02% for bending angle
  0.02% for refractivity
  0.03% for pressure
  <3 m for geop. height
  0.05 K for temperature

- **Climate change signal** detection study for RO (*Lackner et al.*, 2011)
  ~15 m/decade geop.height increase — 1.5–3 m/decade UTLS **struc.Unc.**
  ~0.3 K/decade warming in UT — 0.02 K/decade UT **struc.Unc.**
  ~0.6 K/decade cooling in LS tropics — 0.07 K/decade LS **struc.Unc.**

- **GCOS stability requirement for air temperature** (*GCOS*, 2006)
  0.05 K/decade UT
  0.1 K/decade LS

[a]For different timescales the given (random) uncertainties scale as $\sigma(\Delta t/\Delta t_{\mathrm{target}})^{3/2}$,
where Δt is 7 years and $\Delta t_{\mathrm{target}}$ is the target time [*Leroy et al.*, 2008]
(e.g., σ = 3 m/7 yr translates to an error of 2.5 m/10 yr for a 10-year time series)

Conclusions and Outlook

- Estimation of structural uncertainty from spread of anomaly trends and finally from the **standard deviation of the all-center mean trend**
- Structural uncertainty of RO CHAMP data from 6 processing centers
- Low structural uncertainty: tropics to mid-latitude UTLS, 50S to 50N below 25km
- GPS RO can be used for climate trend assessment within this region meeting GCOS requirements
- Higher structural uncertainty above 25 km and at high latitudes
- Reflect different bending angle initialization approaches including different high altitude background information
- RO processing systems undergo continuous development
- Further improvements are expected enlarging the range of low uncertainty

THANK YOU !

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