Combined SPARC Data Requirements/SPIN
mid-term review meeting
ESRIN, Frascati, February 2013

Temperature ECV Review

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The Task

The contractor **shall** perform a review of the requirements as specified in *Systematic Observation Requirements for Satellite-Based Products for Climate – GCOS 107* on stratospheric temperature and water vapour ECVs (e.g. are they realistic and can they be measured by current satellite instrumentation?, are the needs of the climate modelling community adequately addressed?) and generate a new User Requirements Document for these two ECV parameters. The contractor **shall** as well describe all needed data for geophysical validation and the planned validation approach in a dedicated report (Product Validation Plan).

Guiding thoughts and methodology very similar to those for water vapour as presented yesterday, but now in a better position to quantitatively assess the measurement requirements.

GCOS requirements

As detailed in GCOS-107 and later updated in GCOS-154

Variable/ Parameter	Horizontal resolution	Vertical Resolution	Temporal resolution	Systematic error	Stability
Stratospheric temperature profile	100 km along-track	2 km	4 hours	0.5K	0.05K per decade
Temperature of deep atmospheric layers	100 km	5 km	Monthly averages	0.2K	0.02K per decade

GCOS-154 uses the term *accuracy* which they define as the requirement for closeness of agreement between product values and true values. This is equivalent to our term *systematic error*.

GRUAN requirements

GRUAN has not yet done the analysis to distinguish between different potential uses of the temperature measurements in defining the temperature measurement requirements.

Target	Vertical resolution	Random error	Systematic error	Stability
State-of-the-art capability	100m or better below 30km altitude, 500m above 30km altitude.	≤0.2K	1K	0.05 K per decade
GRUAN goal	100m or better below 30km altitude, 500m above 30km altitude	≤0.2K	≤0.2K	Better than 0.05 K per decade

WMO/CEOS Rolling Review of Requirements

Layer	Application	Horiz. Res.	Vert. Res.	Temporal resolution	Random error
Lower stratosphere	Global modelling	Goal: 50km Min: 500km	Not listed	Goal: 3h Min: 12h	Goal: 0.5K Min: 3K
	Global NWP	Goal: 15km Min: 500km	Goal: 300m Min: 3km	Goal: 1h Min: 12h	Goal: 0.5K Min: 3K
	High resolution NWP	Goal: 10km Min: 100km	Goal: 1km Min: 3km	Goal: 15min Min: 6h	Goal: 0.5K Min: 3K
	SPARC	Goal: 50km Min: 500km	Goal: 500m Min: 2km	Goal: 6h Min: 3d	Goal: 0.5K Min: 1K
	Synoptic meteorology	Goal: 20km Min: 200km	Goal: 100m Min: 2km	Goal: 3h Min: 12h	Goal: 0.5K Min: 3K
	Climate-AOPC	Goal: 100km Min: 500km	Goal: 2km Min: 3km	Goal: 3h Min: 6h	Goal: 0.5K Min: 2K
Upper stratosphere	Global modelling	Goal: 50km Min: 500km	Not listed	Goal: 3h Min: 12h	Goal: 1K Min: 3K
	Global NWP	Goal: 50km Min: 500km	Goal: 300m Min: 3km	Goal: 1h Min: 24h	Goal: 0.5K Min: 5K
	SPARC	Goal: 50km Min: 500km	Goal: 500m Min: 2km	Goal: 6h Min: 3d	Goal: 0.5K Min: 1K
	Climate-AOPC	Goal: 100km Min: 500km	Goal: 2km Min: 3km	Goal: 3h Min: 6h	Goal: 0.5K Min: 3K

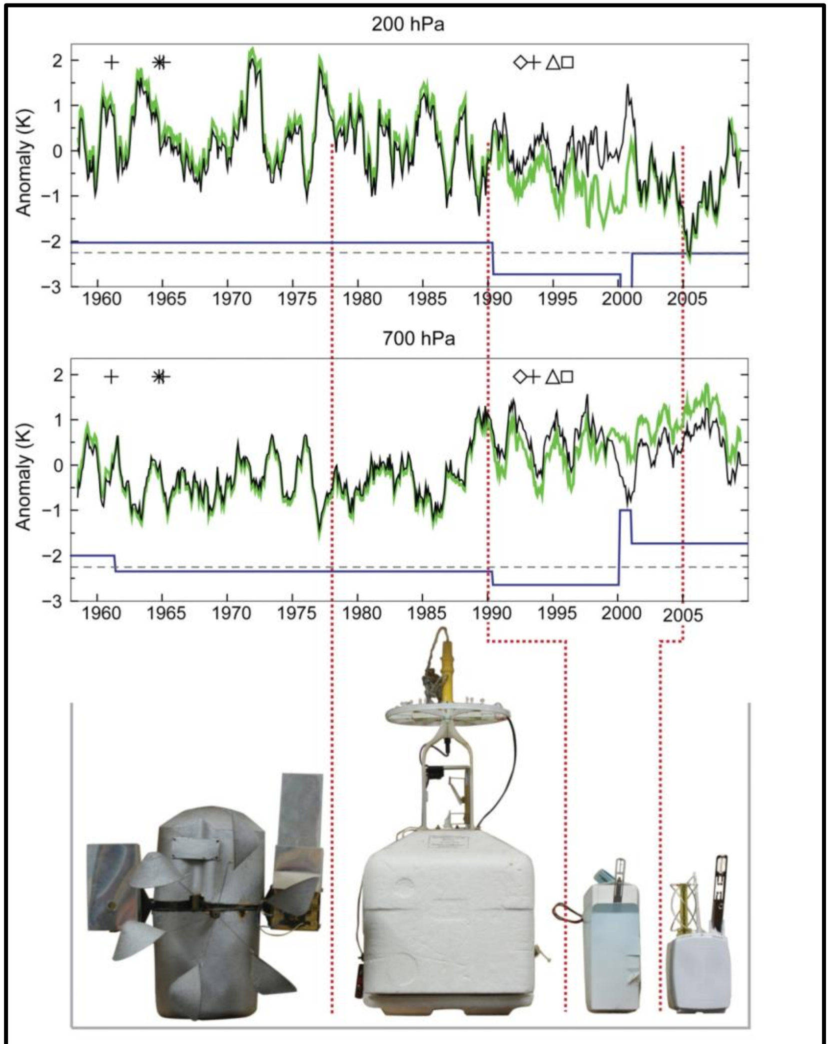
Database does not list values for stability

Currently achievable measurement attributes

Radiosondes

- Operational radiosondes with a vertical resolution of tens of metres, random error of ≤0.2 K and systematic error ≤0.5 K below ~30 km, generally meet the vertical resolution and measurement error requirements detailed above.
- Operational radiosonde measurements typically only archived at WMO standard levels → value of storing high resolution radiosonde data → SPARC Date Centre holdings.
- Temporal sampling is generally every 12 hours, which is not adequate.
- Horizontal sampling is extremely inhomogeneous and definitely not compliant with the requirements (Seidel, D.J.; Sun, B.; Pettey, M. and Reale, A., Global radiosonde balloon drift statistics, *JGR*, 116, D07102, doi:07110.01029/02010JD014891, 2011.
- Radiosondes limited to ~30 km altitude; generally only provide reasonable coverage up to 25 km.

Currently achievable measurement attributes



Radiosondes (continued)

- Stability is compromised by changes in instrument or operating practice.
- Various quality-controlled radiosonde data sets are available which can be compared to assess their consistency.
- Resulting uncertainties in potential drifts certainly exceed the GCOS requirement of 0.05 K/decade.

Currently achievable measurement attributes

GPS Radio Occultation (RO)

- Space-based GPS RO network provides critical supplement to the radiosonde network for lower stratospheric temperature.
- Measurement uncertainty of ≤0.1 K for altitudes below 20 km, and 0.2 K in dry temperature between 4 and 35 km → meets error requirements for temperature profiles in upper troposphere and lower stratosphere.
- Errors increase with altitude, especially above 35 km.
- Vertical resolution of better than 1.5 km → meets climate-related vertical resolution requirements of GCOS, but not the process or NWP-related requirements of GRUAN or WMO.
- Horizontal and temporal resolution depends on the number of receivers; although not currently adequate, it is improving.
- Exceptional long-term stability.

Currently achievable measurement attributes

Limb viewing research satellites

- Inhomogeneous record of stratospheric temperature profiles.
- Solar occultation technique cannot provide global coverage.
- Useful records from thermal emission or stellar occultation.
- Thermal emission sounders → vertical resolution generally no better than 3-4 km → not adequate to meet the requirements described above.
- Can be used to anchor operational nadir-sounding temperatures.
- Higher vertical resolution possible with stellar occultation (GOMOS).
- Horizontal resolution is generally around 300 km due to horizontal smearing in the limb.
- Horizontal and temporal sampling generally inadequate.
- Measurement uncertainty ~0.5 K → in principle adequate.
- Long-term stability is not assured.

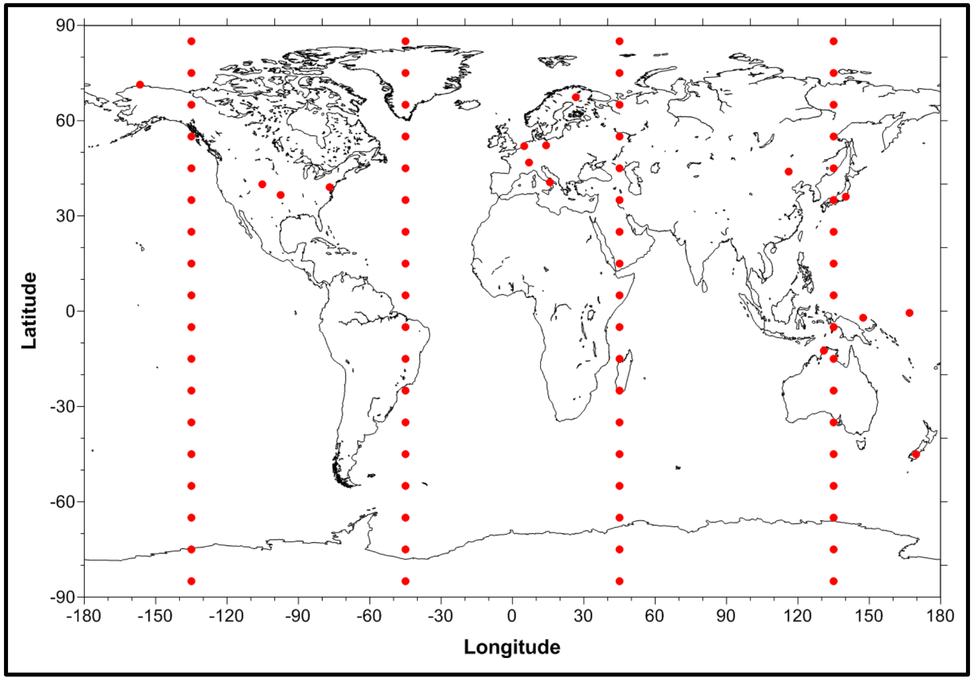
Currently achievable measurement attributes

Nadir viewing operational satellites

- Nadir-viewing operational satellites in the MSU/SSU/AMSU series provide temperatures of deep atmospheric layers.
- Relatively coarse vertical resolution (about 5 km, after over-sampling).
- Reasonably high horizontal and temporal resolution (roughly 500 km and global sampling every 6 hours).
- Main problem is long-term stability given rapid drift in orbits and short (several years) lifetime of individual instruments.
- Various retrievals of MSU Channel 4 in lower stratosphere (15-20 km) can be compared with homogenised radiosonde or GPS RO measurements.
- In middle and upper stratosphere two retrievals of SSU Channels 1 (25-35 km), 2 (35-45 km), and 3 (40-50 km) disagree significantly.
- Long-term stability of nadir-based middle and upper stratospheric temperature measurements is highly questionable.

Requirements rationale and traceability

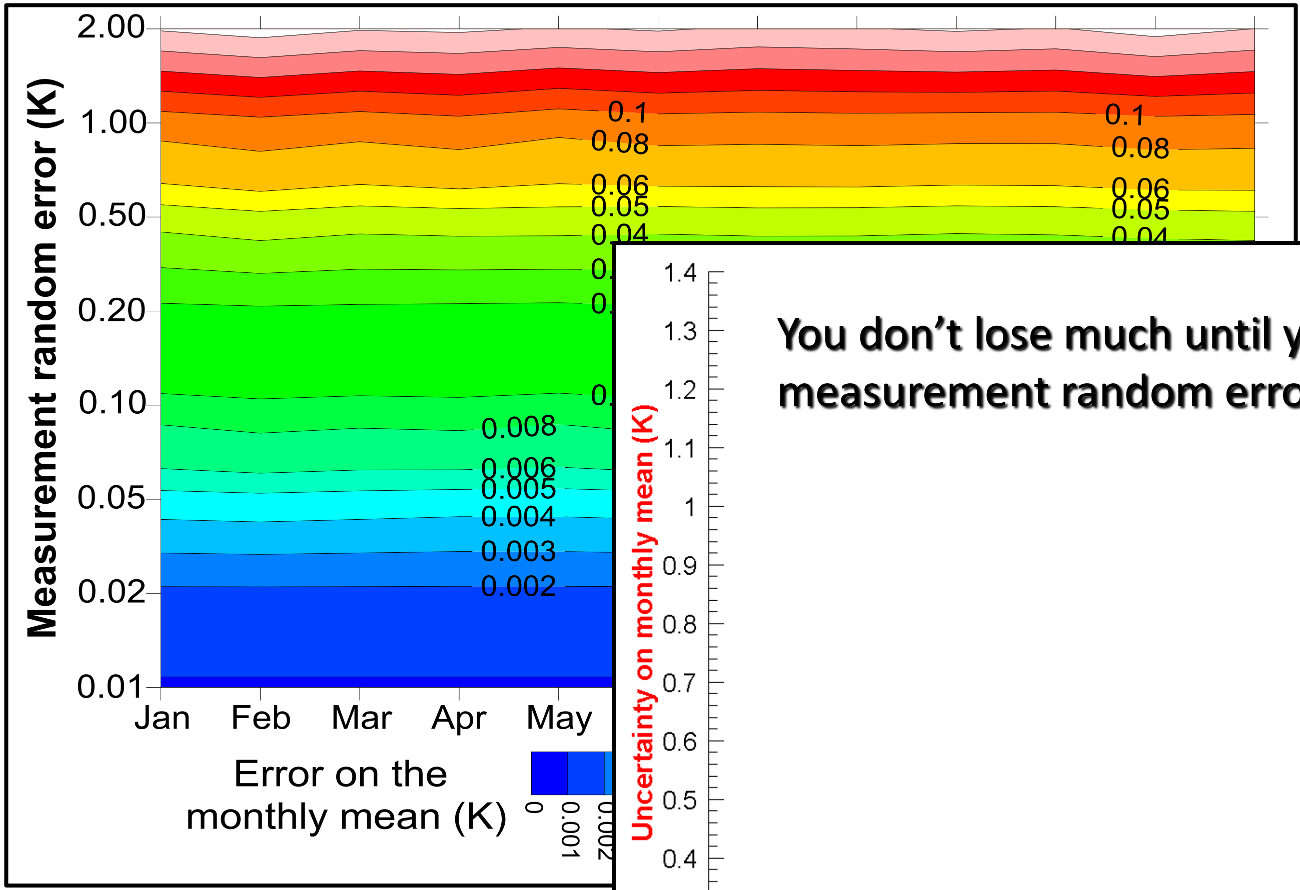
Extending the analysis of Seidel, D.J. and Free, M., Measurement Requirements for Climate Monitoring of Upper-Air Temperature Derived from Reanalysis Data, *J. Climate*, 19, 854-871, 2006.

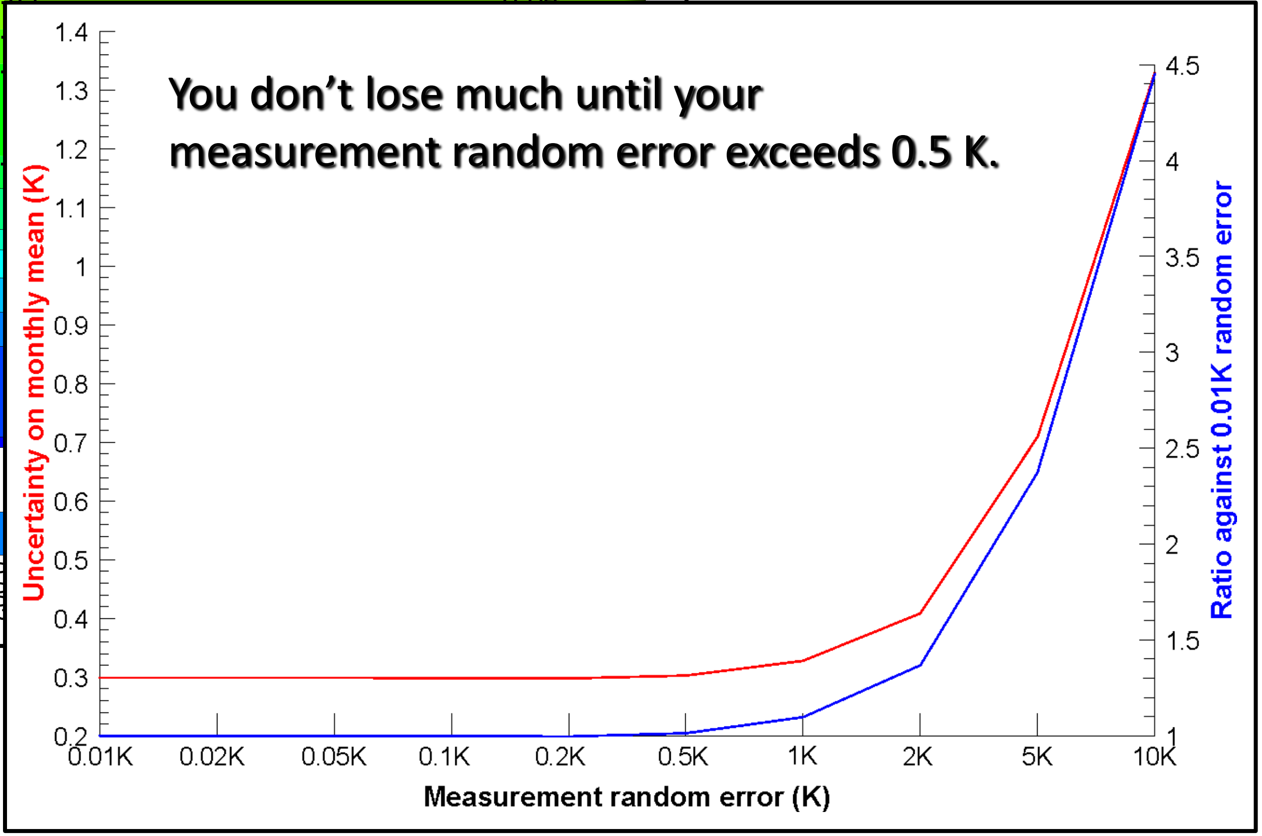


Considered 87 sites and considered how uncertainty on monthly mean temperatures is determined as a function of sampling frequency, random error on each measurement, season and altitude/pressure. Used NCEPCFSR data set (1979-2010, 37 pressure levels, 0.5°x0.5°, every 6 hours).

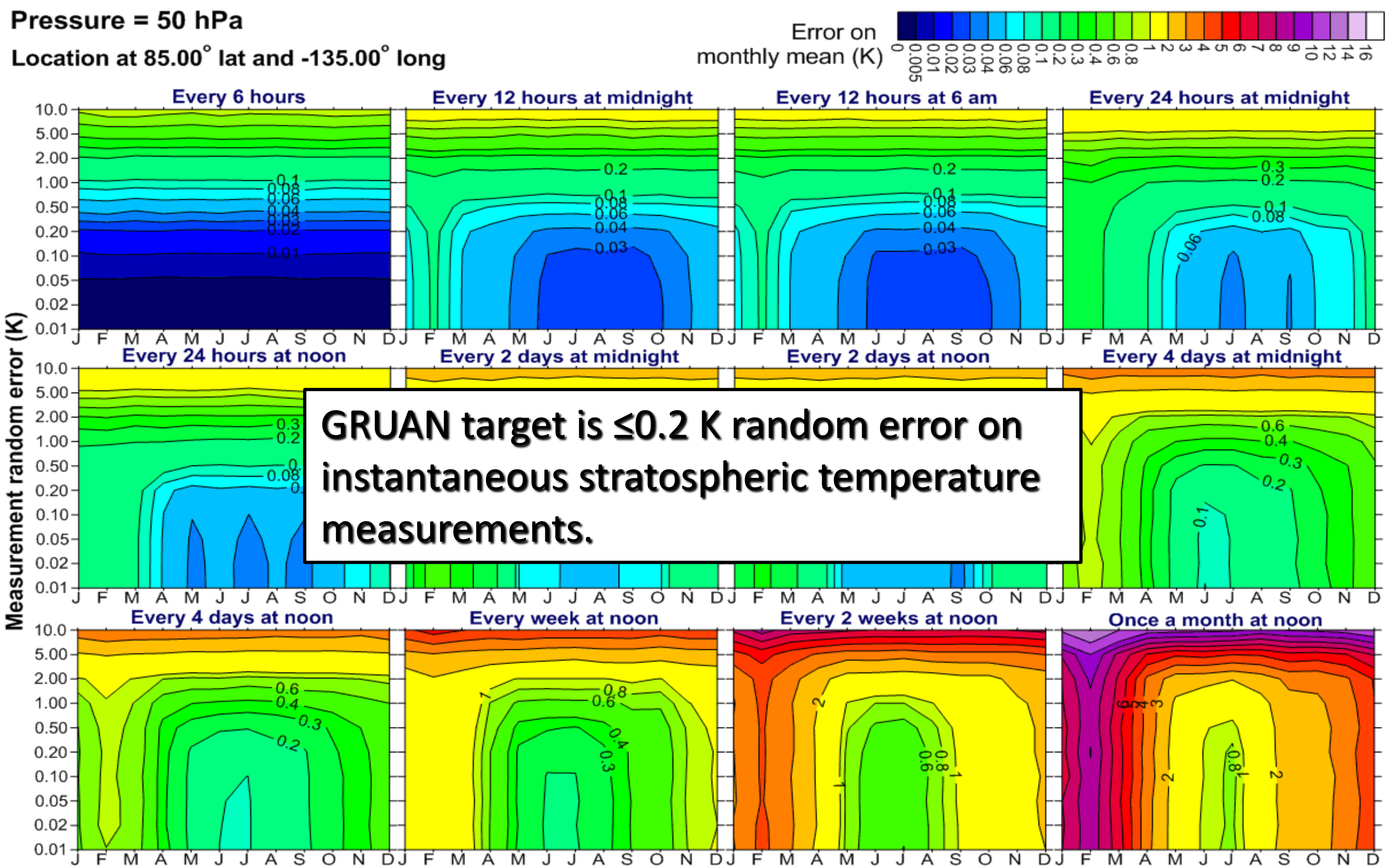
Considered the 'true' monthly mean as that obtained at 6 hourly sampling, 0.01 K random error. Monte Carlo sampling.

Effects of random error



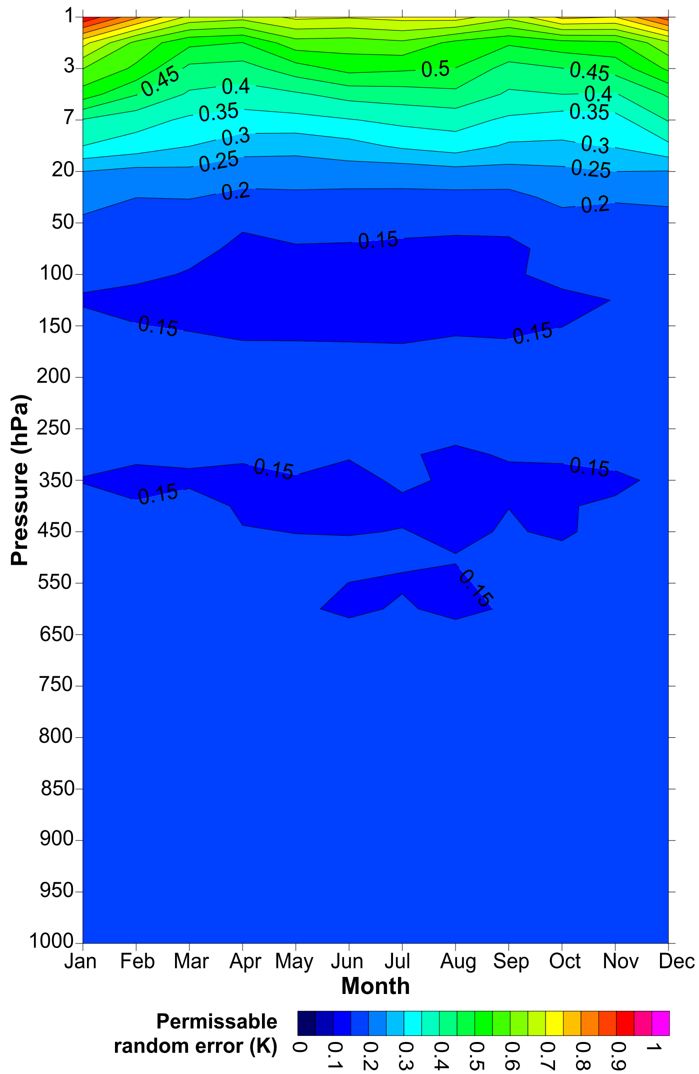


Dependence on sampling frequency and season



GRUAN target is ≤0.2 K random error on instantaneous stratospheric temperature measurements.

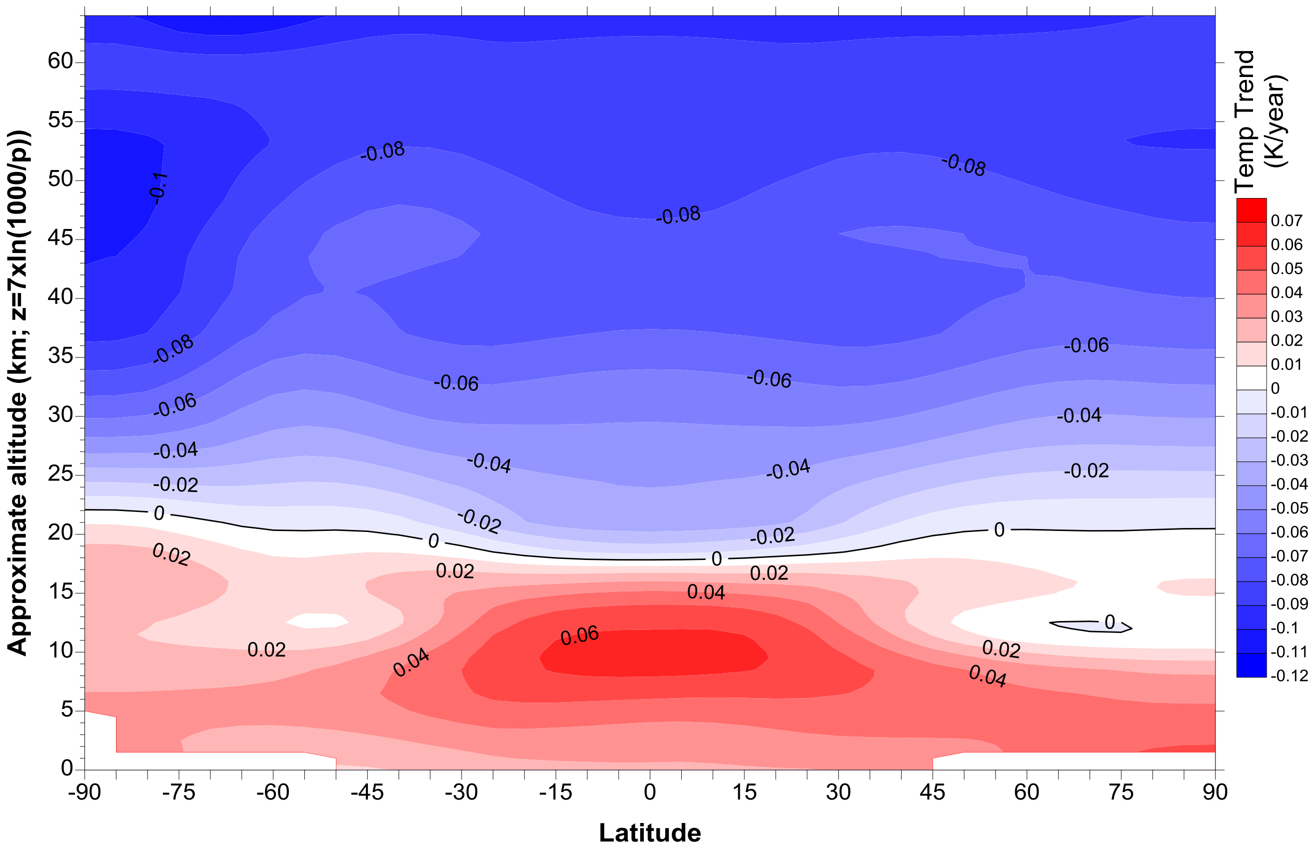
Dependence on altitude/pressure



When sampling every 12 hours at midnight and noon, this figure shows the permissible random errors on individual measurements required to avoid increasing the uncertainty on the monthly mean by more than 10% above the uncertainty on the 'true' monthly mean. 0.5 K is OK in stratosphere but this reduces to 0.25 K at ~20 hPa and to 0.15 K in the free troposphere.

Trend measurement requirements

How long would it take to detect expected trends in upper air temperatures for specified sampling regimens (both in terms of frequency and random error of each measurement)?



Expected temperature trends taken from 11 CCMs running the REF-B2 simulation as part of CCMVal2

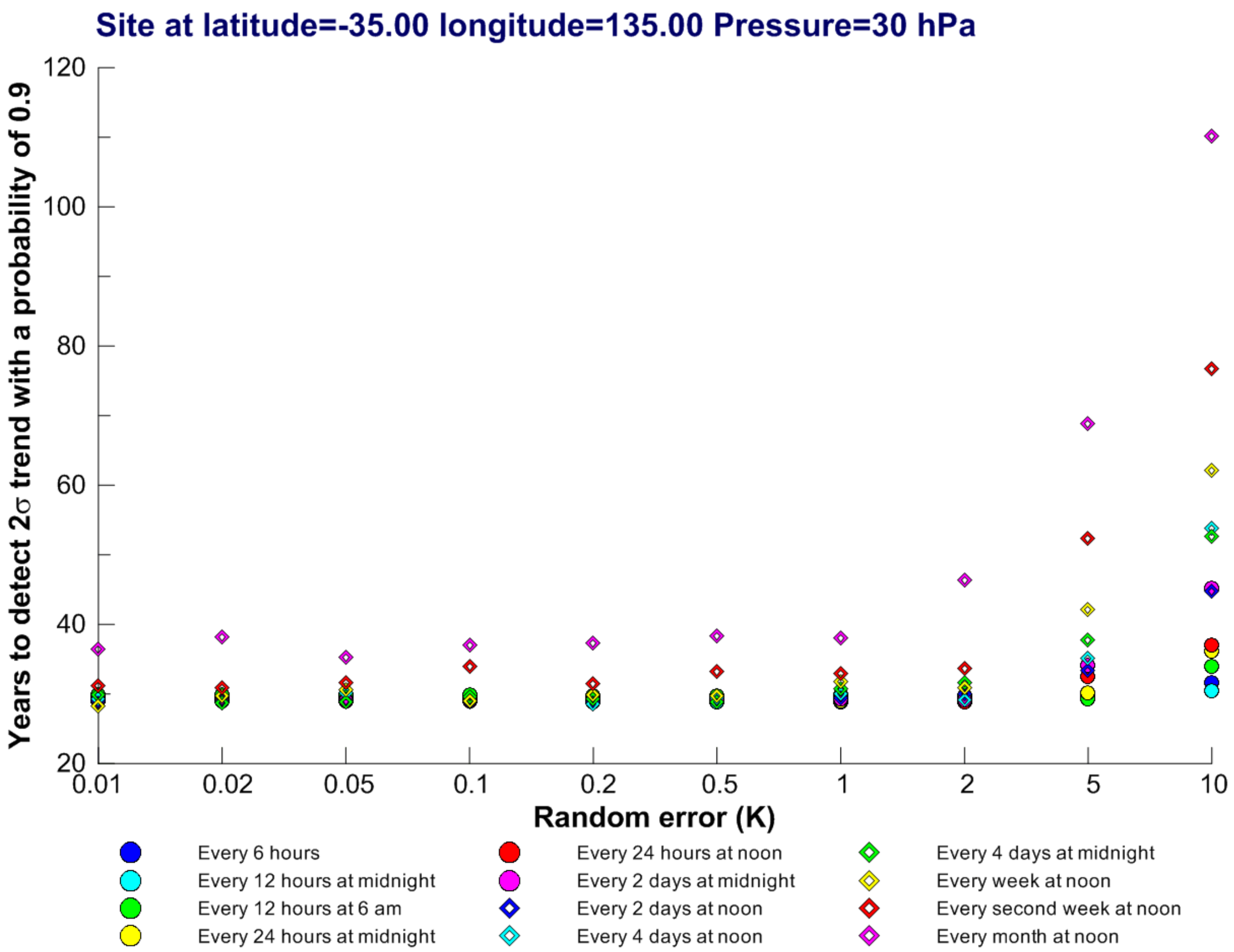
Time to detect trends

The number of years of measurements required to detect a trend at the 95% confidence level with a probability of 0.9 can be approximated by (Whiteman et al., 2011):

$$n* = \left[\frac{3.3\sigma_N}{|\omega_0|}\sqrt{\frac{1+\phi_N}{1-\phi_N}}\right]^{2/3}$$

where σ_N is the standard deviation of the total noise in the time series i.e. the standard deviation of the residuals after the application of the regression model, ω_0 is the trend magnitude in K/year, and φ_N is the autocorrelation of the noise. After the calculated number of years, there is a 90% probability that a trend of the correct sign will have been detected if we assume that detecting a trend means identifying a trend at the 95% confidence level.

One example


Site at latitude=-35.00 longitude=135.00 Pressure=30 hPa
Years to detect 2σ trend with a probability of 0.9
120
100
80
60
40
20
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
Random error (K)
Every 6 hours
Every 12 hours at midnight
Every 12 hours at 6 am
Every 24 hours at midnight
Every 24 hours at noon
Every 2 days at midnight
Every 2 days at noon
Every 4 days at noon
Every 4 days at midnight
Every week at noon
Every second week at noon
Every month at noon

Synthesis

	60°S to 90°S (12)	30°S to 60°S (13)	0°S to 30°S (15)	0°N to 30°N (12)	30°N to 60°N (21)	60°N to 90°N (14)
1 hPa	Every: 6 hours: 9 12 hours at midnight: 7 12 hours at 6 am: 10 24 hours at midnight: 8 24 hours at noon: 7 2 days at midnight: 6 2 days at noon: 7 4 days at noon: 6 4 days at midnight: 7 week at noon: 5 second week at noon: 7 month at noon: 1	Every: 6 hours: 0 12 hours at midnight: 1 12 hours at 6 am: 0 24 hours at midnight: 1 24 hours at noon: 0 2 days at midnight: 1 2 days at noon: 0 4 days at noon: 0 4 days at midnight: 1 week at noon: 0 second week at noon: 0 month at noon: 0	Every: 6 hours: 15 12 hours at midnight: 10 12 hours at 6 am: 13 24 hours at midnight: 11 24 hours at noon: 11 2 days at midnight: 10 2 days at noon: 11 4 days at noon: 12 4 days at midnight: 13 week at noon: 13 second week at noon: 13 month at noon: 8	Every: 6 hours: 9 12 hours at midnight: 8 12 hours at 6 am: 7 24 hours at midnight: 9 24 hours at noon: 9 2 days at midnight: 9 2 days at noon: 9 4 days at noon: 10 4 days at midnight: 10 week at noon: 12 second week at noon: 11 month at noon: 10	Every: 6 hours: 5 12 hours at midnight: 4 12 hours at 6 am: 5 24 hours at midnight: 5 24 hours at noon: 3 2 days at midnight: 5 2 days at noon: 2 4 days at noon: 3 4 days at midnight: 5 week at noon: 3 second week at noon: 3 month at noon: 0	Every: 6 hours: 0 12 hours at midnight: 0 12 hours at 6 am: 0 24 hours at midnight: 0 24 hours at noon: 0 2 days at midnight: 0 2 days at noon: 0 4 days at noon: 0 4 days at midnight: 0 week at noon: 0 second week at noon: 0 month at noon: 0
10 hPa	Every: 6 hours: 2 12 hours at midnight: 2 12 hours at 6 am: 2 24 hours at midnight: 2 24 hours at noon: 2 2 days at midnight: 2 2 days at noon: 2 4 days at noon: 1 4 days at midnight: 2 week at noon: 1 second week at noon: 0 month at noon: 0	Every: 6 hours: 3 12 hours at midnight: 3 12 hours at 6 am: 3 24 hours at midnight: 3 24 hours at noon: 4 2 days at midnight: 3 2 days at noon: 3 4 days at noon: 3 4 days at midnight: 3 week at noon: 3 second week at noon: 3 month at noon: 0	Every: 6 hours: 13 12 hours at midnight: 12 12 hours at 6 am: 12 24 hours at midnight: 12 24 hours at noon: 12 2 days at midnight: 12 2 days at noon: 13 4 days at noon: 13 4 days at midnight: 13 week at noon: 14 second week at noon: 13 month at noon: 11	Every: 6 hours: 12 12 hours at midnight: 12 12 hours at 6 am: 12 24 hours at midnight: 11 24 hours at noon: 12 2 days at midnight: 12 2 days at noon: 12 4 days at noon: 12 4 days at midnight: 12 week at noon: 12 second week at noon: 11 month at noon: 10	Every: 6 hours: 14 12 hours at midnight: 14 12 hours at 6 am: 14 24 hours at midnight: 14 24 hours at noon: 14 2 days at midnight: 14 2 days at noon: 14 4 days at noon: 13 4 days at midnight: 14 week at noon: 12 second week at noon: 8 month at noon: 2	Every: 6 hours: 0 12 hours at midnight: 0 12 hours at 6 am: 0 24 hours at midnight: 0 24 hours at noon: 0 2 days at midnight: 0 2 days at noon: 0 4 days at noon: 0 4 days at midnight: 0 week at noon: 0 second week at noon: 0 month at noon: 0
50 hPa	Every: 6 hours: 0 12 hours at midnight: 0 12 hours at 6 am: 0 24 hours at midnight: 0 24 hours at noon: 0 2 days at midnight: 0 2 days at noon: 0 4 days at noon: 0 4 days at midnight: 0 week at noon: 0 second week at noon: 0 month at noon: 0	Every: 6 hours: 0 12 hours at midnight: 0 12 hours at 6 am: 0 24 hours at midnight: 0 24 hours at noon: 0 2 days at midnight: 0 2 days at noon: 0 4 days at noon: 0 4 days at midnight: 0 week at noon: 0 second week at noon: 0 month at noon: 0	Every: 6 hours: 7 12 hours at midnight: 7 12 hours at 6 am: 6 24 hours at midnight: 7 24 hours at noon: 7 2 days at midnight: 7 2 days at noon: 7 4 days at noon: 5 4 days at midnight: 6 week at noon: 9 second week at noon: 5 month at noon: 0	Every: 6 hours: 5 12 hours at midnight: 5 12 hours at 6 am: 5 24 hours at midnight: 6 24 hours at noon: 5 2 days at midnight: 5 2 days at noon: 4 4 days at noon: 4 4 days at midnight: 5 week at noon: 4 second week at noon: 4 month at noon: 0	Every: 6 hours: 0 12 hours at midnight: 0 12 hours at 6 am: 0 24 hours at midnight: 0 24 hours at noon: 0 2 days at midnight: 0 2 days at noon: 0 4 days at noon: 0 4 days at midnight: 0 week at noon: 0 second week at noon: 0 month at noon: 0	Every: 6 hours: 0 12 hours at midnight: 0 12 hours at 6 am: 0 24 hours at midnight: 0 24 hours at noon: 0 2 days at midnight: 0 2 days at noon: 0 4 days at noon: 0 4 days at midnight: 0 week at noon: 0 second week at noon: 0 month at noon: 0

Detect trends in 30 years. Random error on each measurement is 1K.

Conclusions

- Reducing random errors is not the only thing to aim for.
- Random errors on temperatures of 0.5 K in the middle stratosphere, 0.25 K in the lower stratosphere and 0.15 K in the free troposphere is sufficient for trend detection.
- In some regions and months you just can't beat natural variability no matter how often you measure and no matter how much you reduce the random error on each measurement.
- Uncertainties on monthly means as a function of random error on each measurement and measurement strategy, are highly dependent on location and season – it therefore might be worth targeting specific seasons for trends detection. More work to be done there.