Sampling strategy and related issues

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Background

- Aim of this work is to develop a strategy to assess the options for an appropriate in-situ sampling routine.
- Some work already published in this area, summarises in following slides.
- Go on to describe proposed methodology and get feedback on the key issues to be addressed.

Recent work (I)

- Dian's J. of Climate paper[1] addressed an number of the key sampling questions using the 6 hourly NCEP/NCAR reanalysis data for 1948 to 2003.
- Data was resampled and/or modified according to different sampling strategies, and the resulting trend statistics compared to the 'true' trend results.
- Results were compared for different locations and vertical levels.

1. Seidel and Free, Journal of Climate, 19, pp 854-871, 2005

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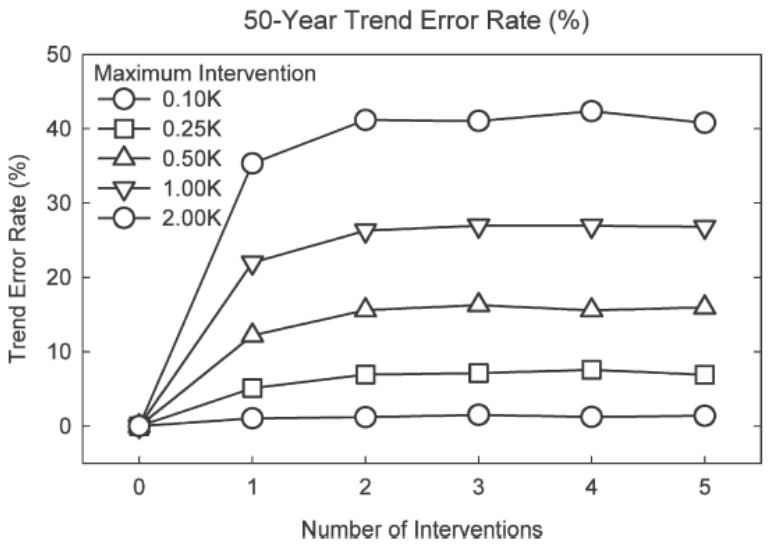
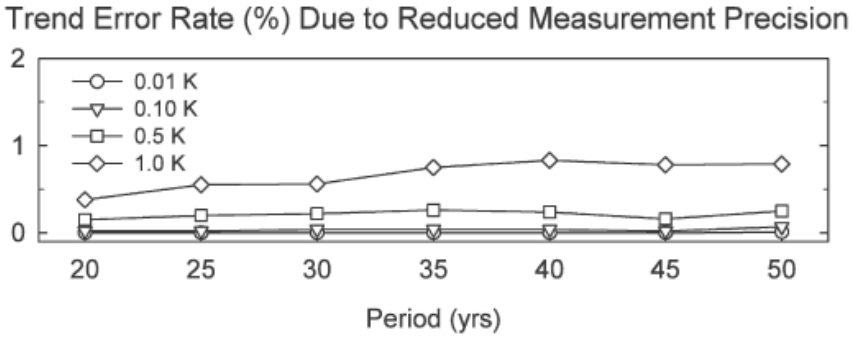
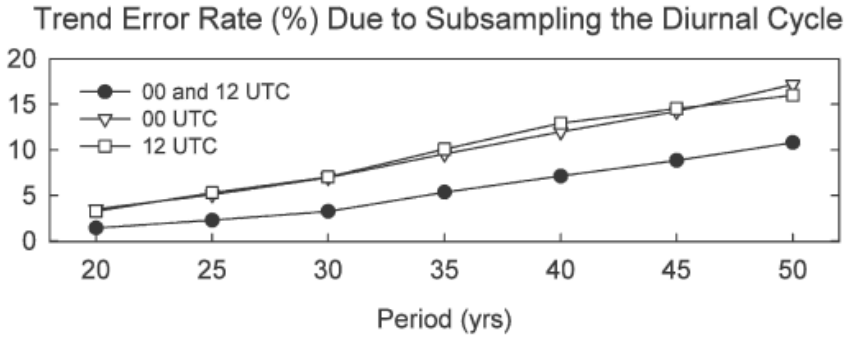
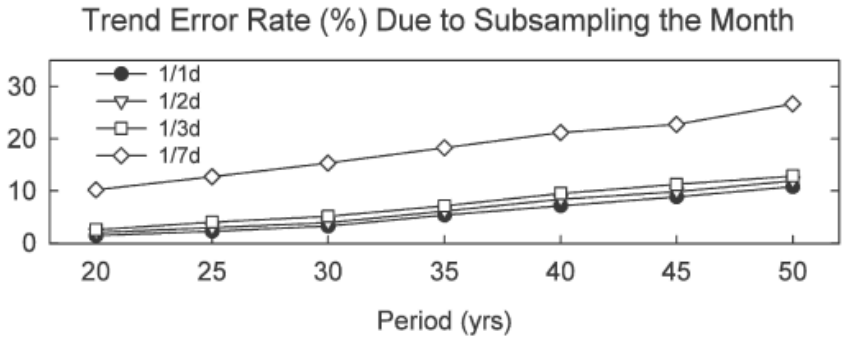
Recent work (II)

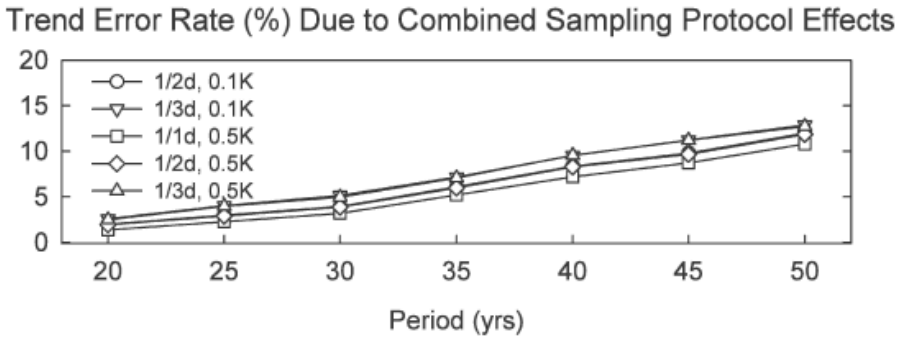
- Addressed effects of
  - Measurement Precision
  - Intra-day sampling
  - Intra-month sampling
  - Interventions (bias changes)





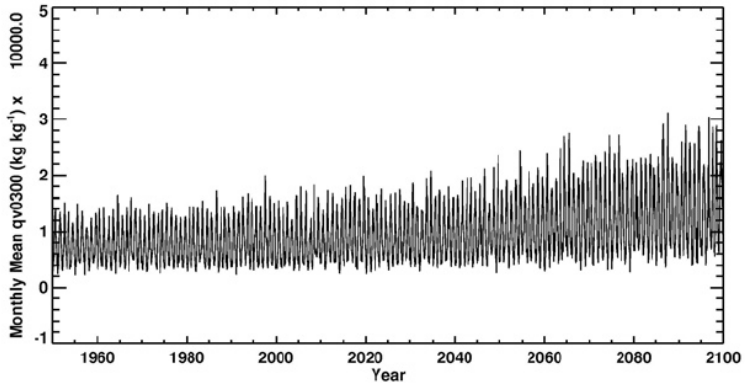






Recent work – water vapour requirements

- Reinout has carried out an assessment of the requirements for UT water vapour trend determination, using the output of regional climate models as the base dataset[2].



Time series of specific humidity at 300 hPa based on the r3 regional climate simulation

- The main conclusion for sampling was that, with a 10% measurement accuracy, it took 45 years of data at a 4 day sampling rate to determine an observed trend within 30% of the true trend.
- The potential of remote sensing to give a (much) higher data rate was highlighted.

2. Boers and van Meijgaard, GRL, 36, L19806, 2009

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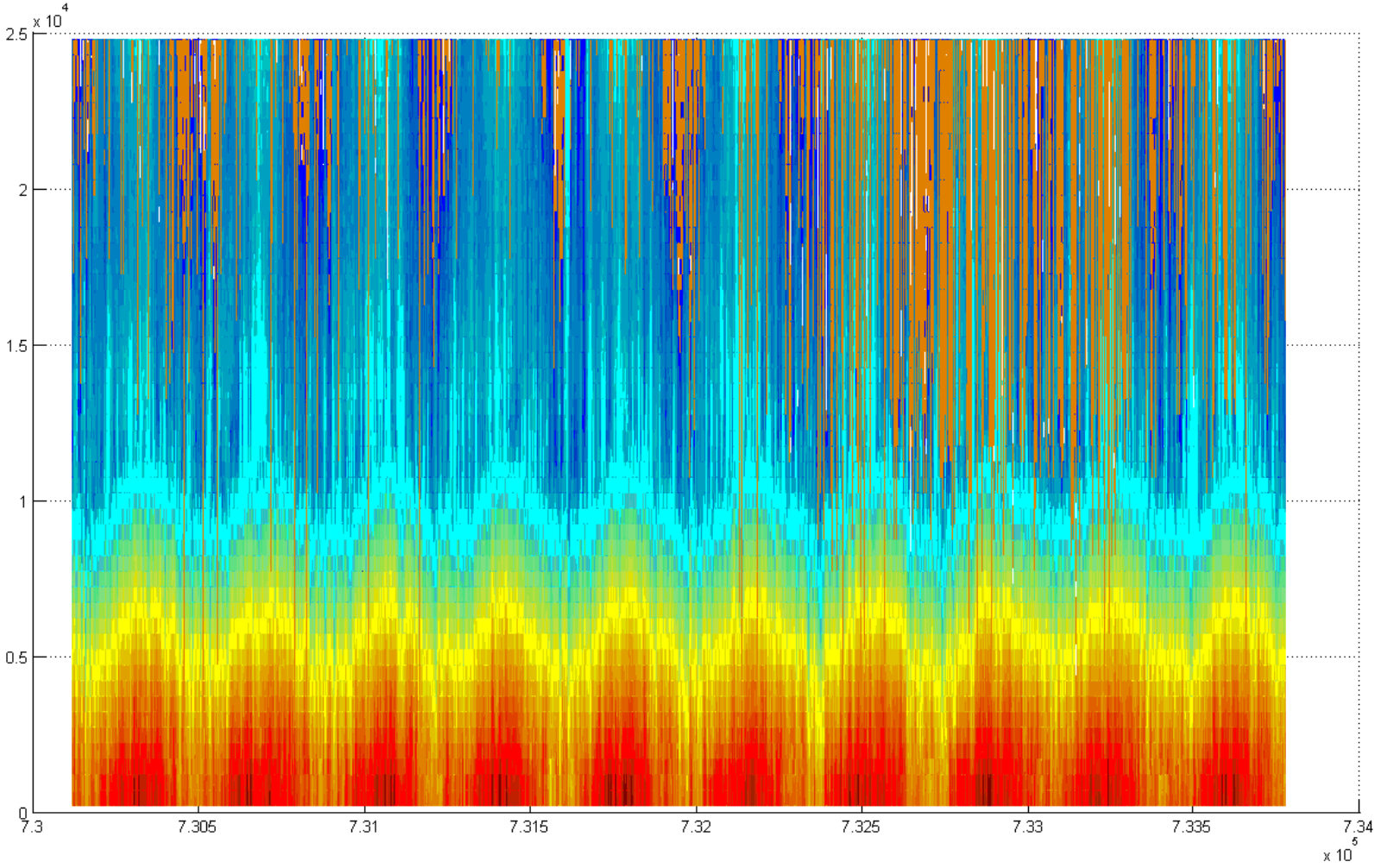
Proposed new assessment strategy

- Model impact of different sampling strategies on trend analyses.
- Use example high density dataset as testcase.
- Use trend analysis tool with appropriate uncertainty determination.
- Resample dataset according to different strategies and look at effect on trend uncertainties.

Lindenburg routine sonde measurements (1999-2008)



Statistical Model for Trend Analysis

The main requirements for an appropriate statistical model are that it should :

- Model the data to take account of the inherent statistical variability.
- Take account of temporal cycles in the data in addition to underlying trends.
- Enable confidence limits to be determined which require no assumptions to be made about the distributions of the measurement uncertainties.
- Be suitable for aggregating data from many sites.
- Standard regression analysis and uncertainties assume normally distributed dataset – almost certainly not the case here.

Bootstrap Resampling (1)

- One statistical method that can be applied in this type of application is bootstrap resampling[3].
- A model function F is fitted to the data such that the values for year i are

$$M_{ij} = F\,(t_{ij}, a, b_j)$$

where t_{ij} is the sample time, a is the underlying trend parameter and bj are the intra-annual factors (ie j = 1…6 for the 3rd order Fourier Series used here).

- A set of residuals can then be determined by comparing this with the measured values V_{ij}

$$R_{ij} = V_{ij} - M_{ij}$$

3. Gardiner et al, Atmos. Chem. Phys., 8, 6719–6727, 2008.

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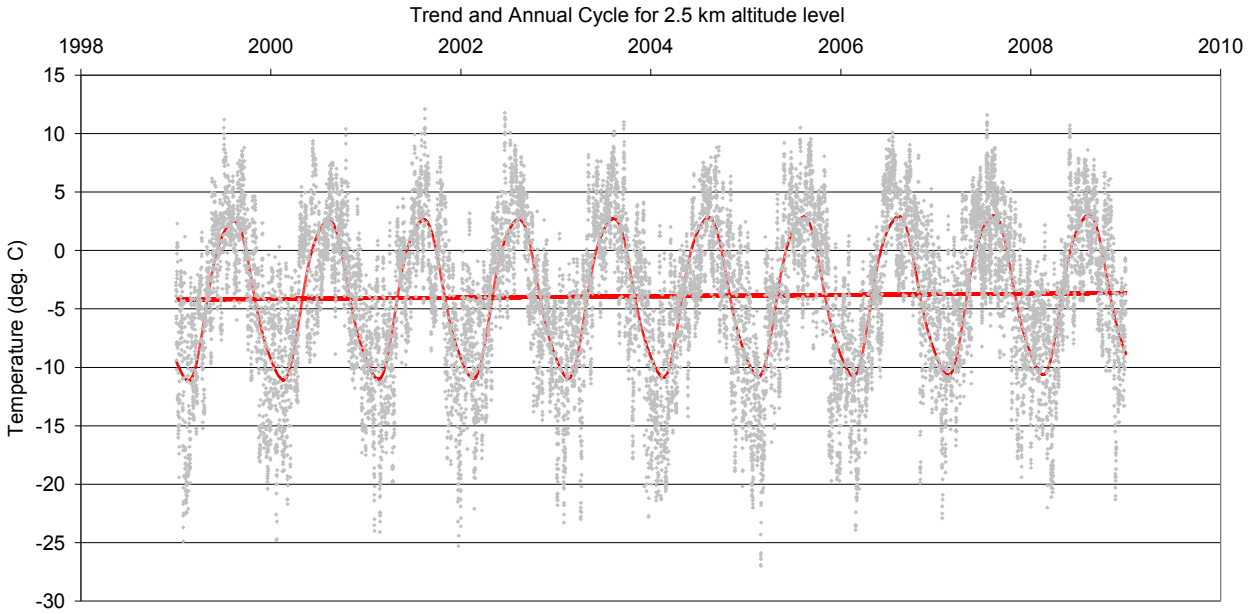
Bootstrap Resampling (2)

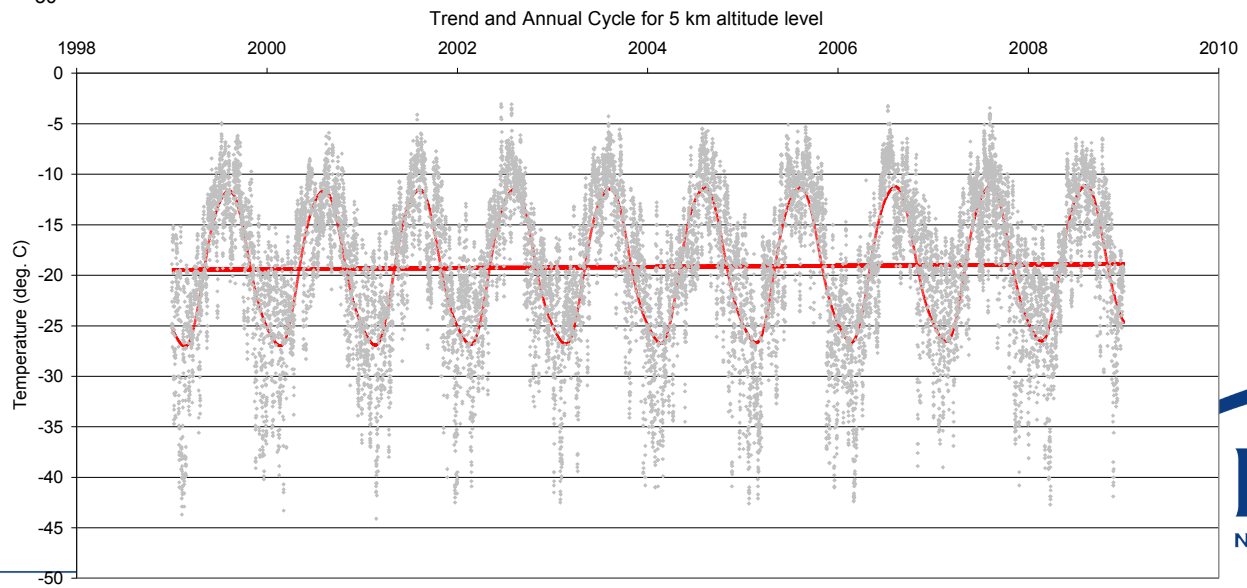
- A new set of simulated data , V^{+}_{ij}, is then created by adding a random sample from the residual data set, R, to each of the model values.

$$V^{+}_{ij} = M_{ij} + R$$

- We can now compute new values for a and b_j using the original model. By repeating this a large number of times we can build up an approximation of the statistical distributions of a and b_j, and hence get an estimate of the associated confidence limits.
- In this way we may determine the uncertainty associated with any of the model parameters without making any assumptions about the statistical distribution of the residuals.

Example bootstrap trend determinations





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Bootstrap analysis results

- For the two examples shown the trend results are as follows :

Level	Trend (deg.C / yr)	95% percentiles	
		Lower	Upper
2.5 km (745 mbar)	5.75×10^{-2}	3.01×10^{-2}	8.41×10^{-2}
5 km (540 mbar)	5.85×10^{-2}	2.84×10^{-2}	8.81×10^{-2}

- Main point to note is not the absolute values, but that the trend is lower than obtained from a regression fit (factor of ~3) and the uncertainty is much larger (factor of ~12) and more realistic given the dataset.
- Method provides a robust way to assess the uncertainties in trend determination for different sampling strategies.

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Possible application of other statistical techniques

- A number of other numerical / statistical techniques are being studied at NPL that may have direct or indirect application to this work.
- One area of interest is the determination of correlation scales in datasets. Possible applications include :
  - Investigating the temporal correlation scale (possibly as an independent route to developing a suitable Model Function).
  - Looking at the vertical correlation scales from profile data to determine appropriate averaging kernels.

Next Steps

- Basic tools in place for sampling strategy assessment.
- Look at effects of different sampling regimes on trend uncertainties – eg daytime only vs nighttime only, reduced sampling densities, others ?
- Consider impact of spatial and temporal correlation lengths on sampling and analysis strategies.
- Look at options for including natural variability on different timescales (ENSO, QBO, etc.), eg through modified model function
- Test conclusions on other measurement datasets and model datasets.
- Carry out similar assessment for water vapour measurements

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Outstanding questions

- Is this a suitable approach to address the sampling questions ?
- Other issues drive sampling strategy – funding, existing requirements, other scientific priorities.
- Using existing dataset introduces existing measurement uncertainties (noise and bias) into the analysis.
- Instrumental noise vs atmospheric variability. How important is measurement precision ?
- Bias (changes) most important factor in incorrect trend determination. How best to incorporate this into assessment ?
- Should we create model datasets based on knowledge of measurement uncertainties and natural variability ?
- How to combine with other measurements with different sample rates ?