Lower Stratospheric Water Vapor Trend Detection – Current Assessment

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Time to Detect Trends

- Number of years to detect trend at the 95% confidence level with 90% probability
- Values required
  - standard deviation of the data
  - autocorrelation of the data
  - magnitude of the anticipated trend

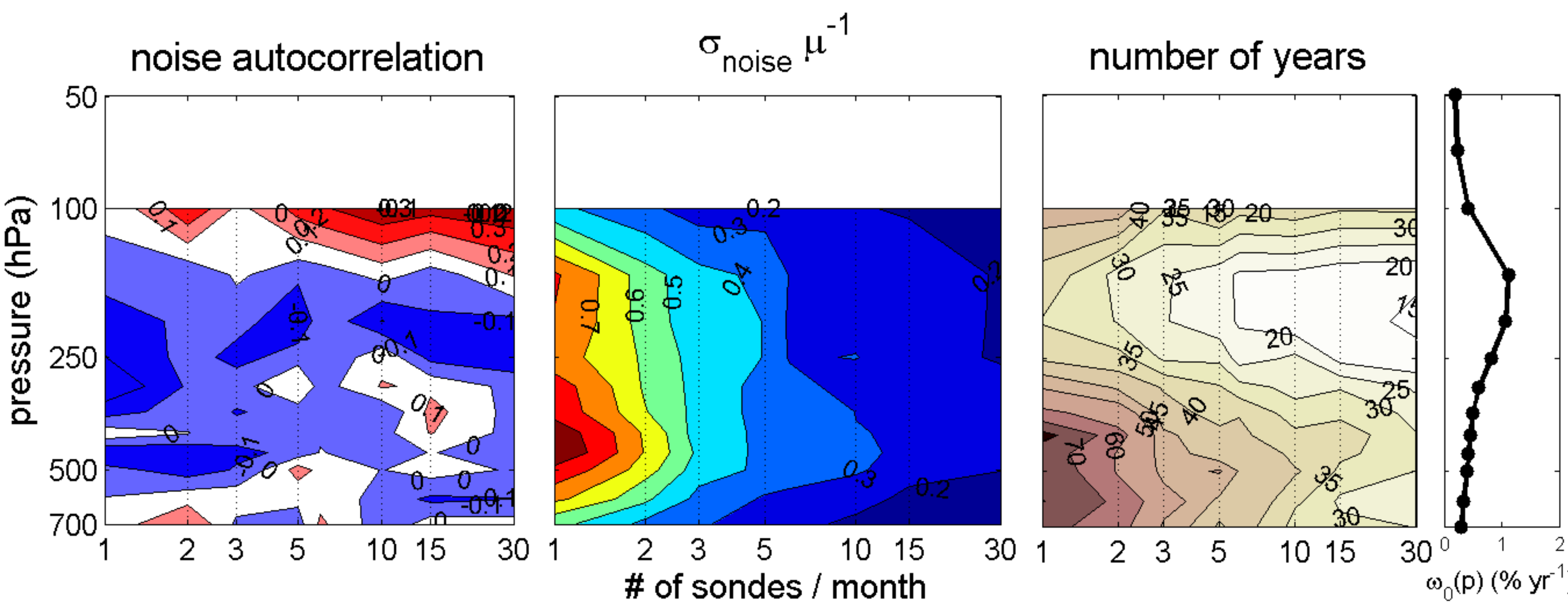
$$n = \left[\frac{3.3\sigma_N}{|\omega_0|} \sqrt{\frac{1+\phi_N}{1-\phi_N}} \right]^{2/3},$$

References:

Tiao, G., et al. (1990), Effects of autocorrelation and temporal sampling schemes on estimates of trend and spatial correlation, J. Geophys. Res., 95(D12), 20,507–20, 517, doi:10.1029/JD095iD12p20507

Weatherhead, E. C., et al. (1998), Factors affecting the detection of trends: Statistical considerations and applications to environmental data, J.Geophys. Res., 103(D14), 17,149–17,161, doi:10.1029/98JD00995.

Boers, R., and E. van Meijgaard (2009), What are the demands on an observational program to detect trends in upper tropospheric water vapor anticipated in the 21st century?, Geophys. Res. Lett., 36, L19806, doi:10.1029/2009GL040044.



Time to Detect Trends-II

- First study focused on the UT
- Speculations from JGR paper
  - trend detection would be easier in the UT than LS
  - Raman water vapor lidar was better suited to UT trend detection than LS
- Results incorporated into GRUAN guide
  - *high random uncertainty is tolerable* but can mask small systematic uncertainty
  - protocols are needed that *tend to randomize sources of systematic uncertainties*
  - to decrease time to detect trend, it is much more important to *increase the frequency of measurement* than to decrease the uncertainty
    - Measurements every 3-4 days optimum

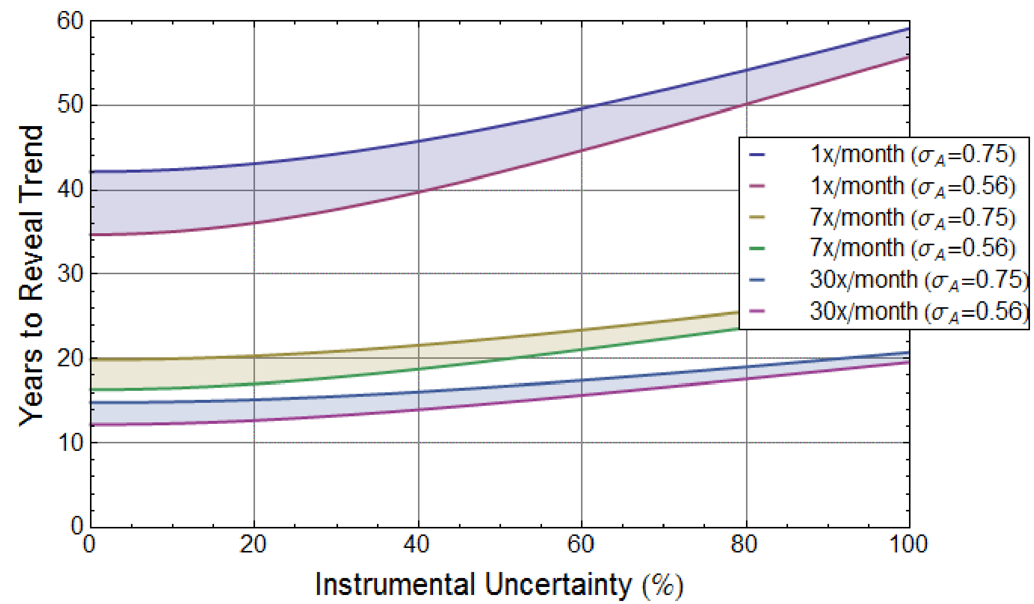


Figure. Years to detect trend versus instrumental measurement uncertainty for differing measurement frequencies and atmospheric variabilities.

Whiteman, D. N., K. C. Vermeesch, L. D. Oman, and E. C. Weatherhead (2011), The relative importance of random error and observation frequency in detecting trends in upper tropospheric water vapor, J. Geophys. Res., 116, D21118, doi:10.1029/2011JD016610.

Boulder FPH time series

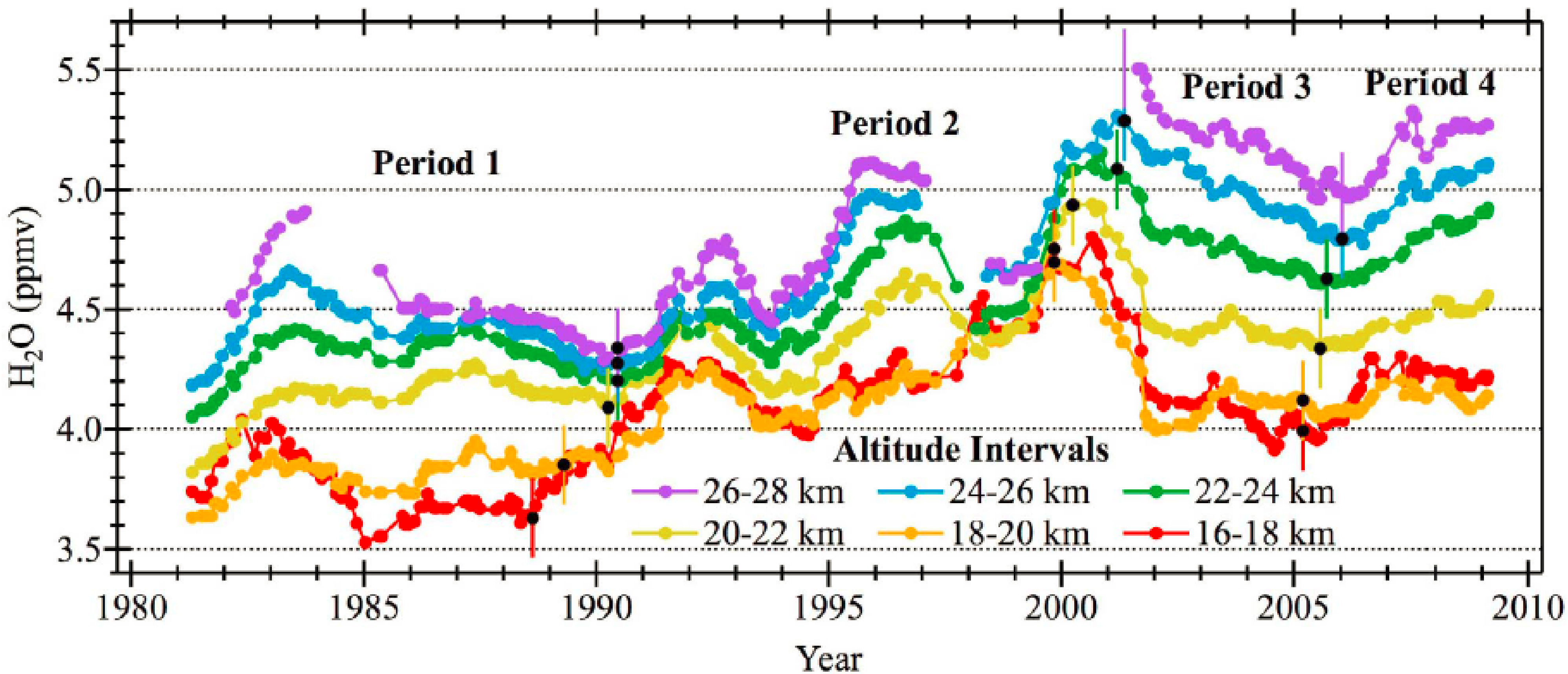
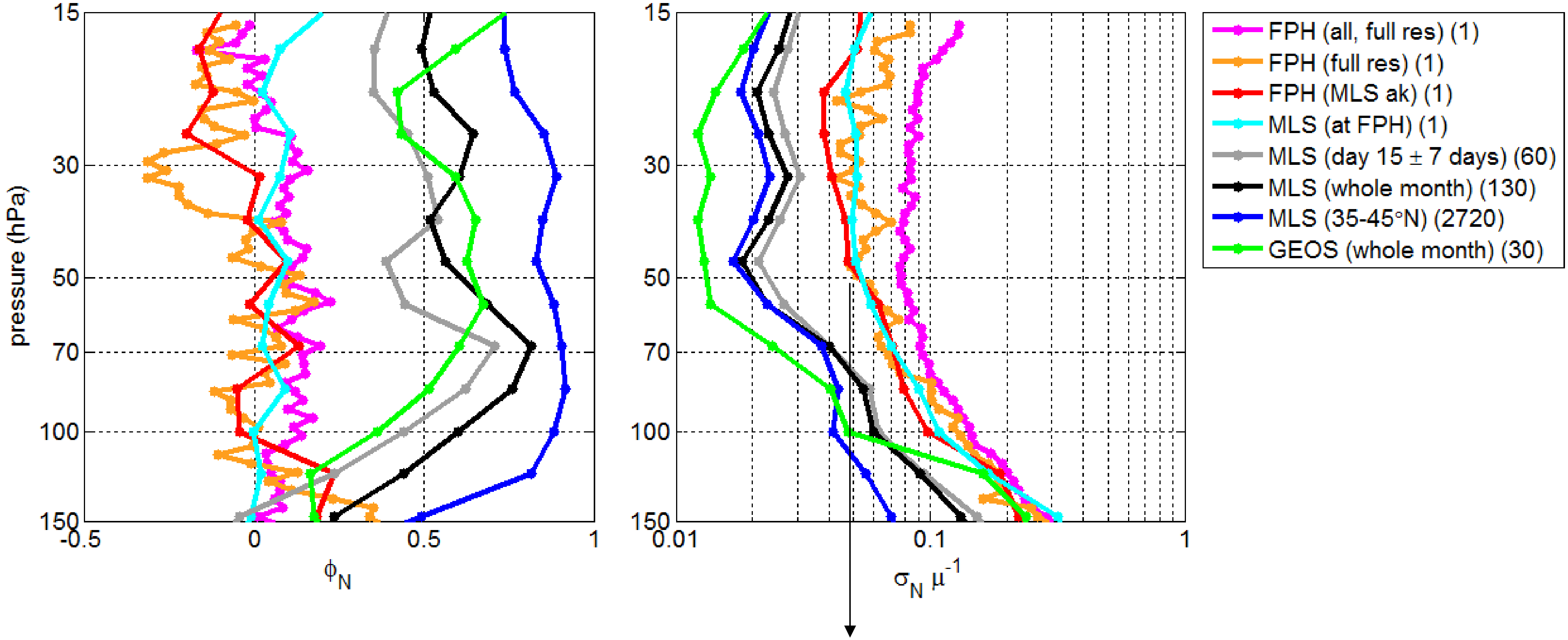


Figure 2. Moving averages of the 2 km water vapor mixing ratio averages in each of the six altitude layers. The averaging window had a width of ±1 year and a threshold of 12 data points to compute an average. Colored vertical bars define the four trend periods for each altitude layer. Moving averages were not calculated for the first and last years of the record. No interpolated or extrapolated values are shown.

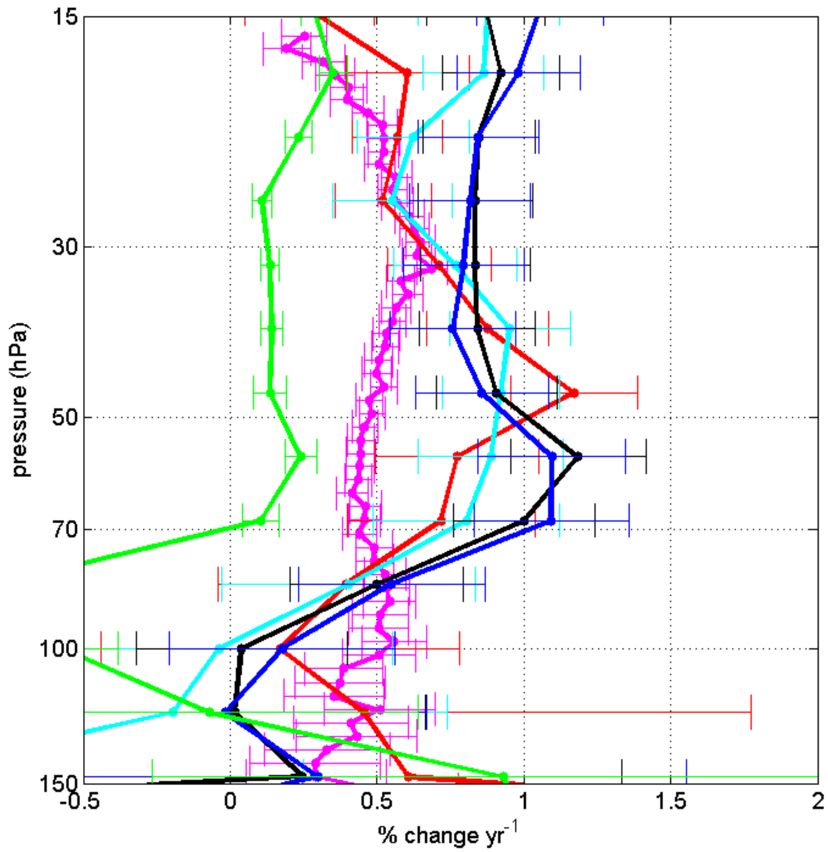
What about the lower stratosphere?

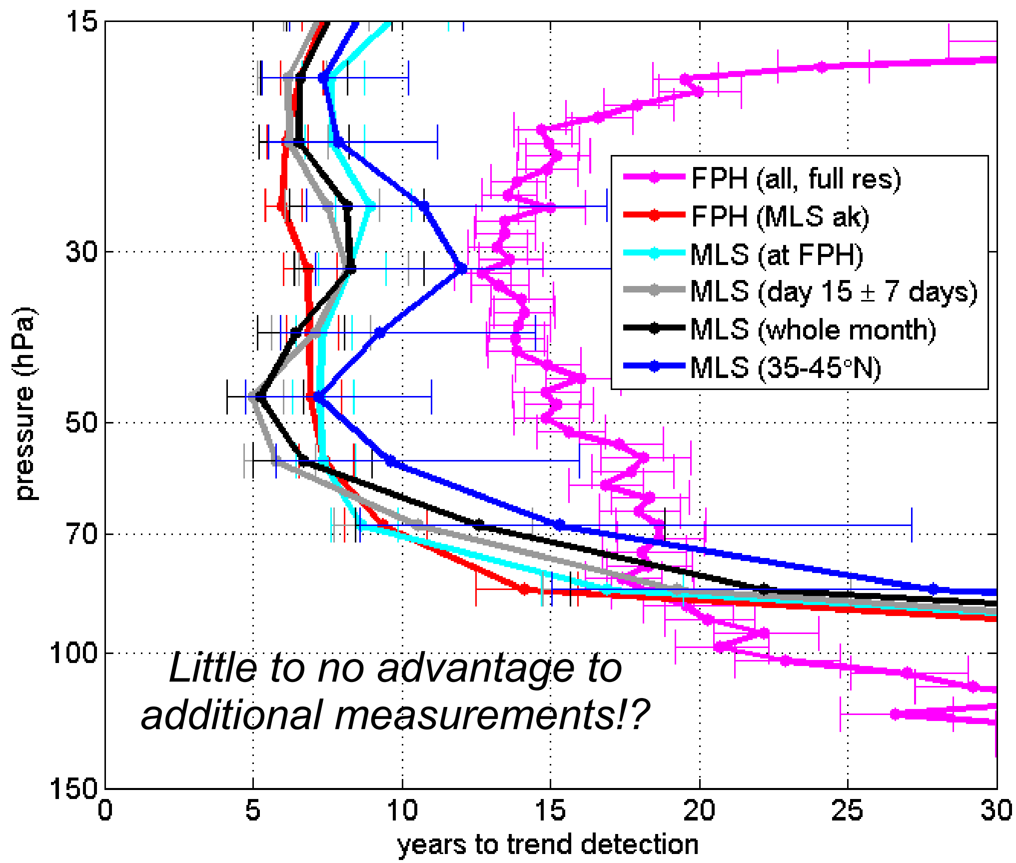
- Use Boulder FPH time series, MLS and GEOS-5 for similar studies in the lower stratosphere (2004 - 2012)
- FPH and MLS in excellent agreement that standard deviation of time series *very* low
  - MLS averaging kernels used on FPH data.



4-5% single measurement *total* variability (compared to 75% in UT) is less than published estimates of instrument uncertainties alone

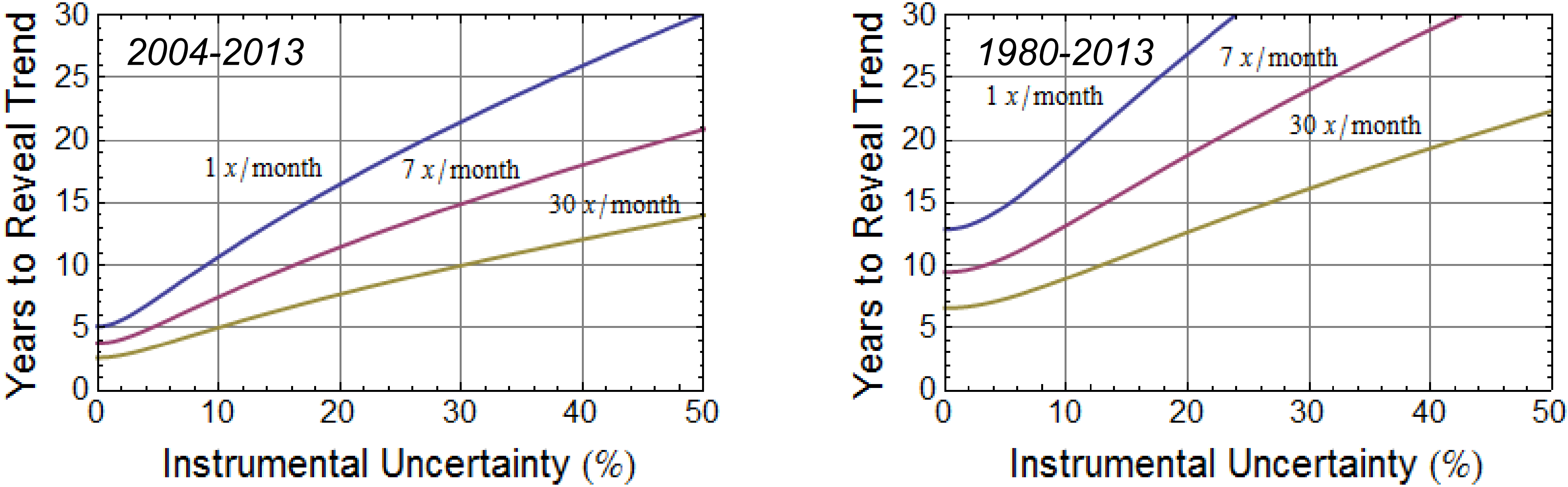
Trends and times to detect trends (Boulder)





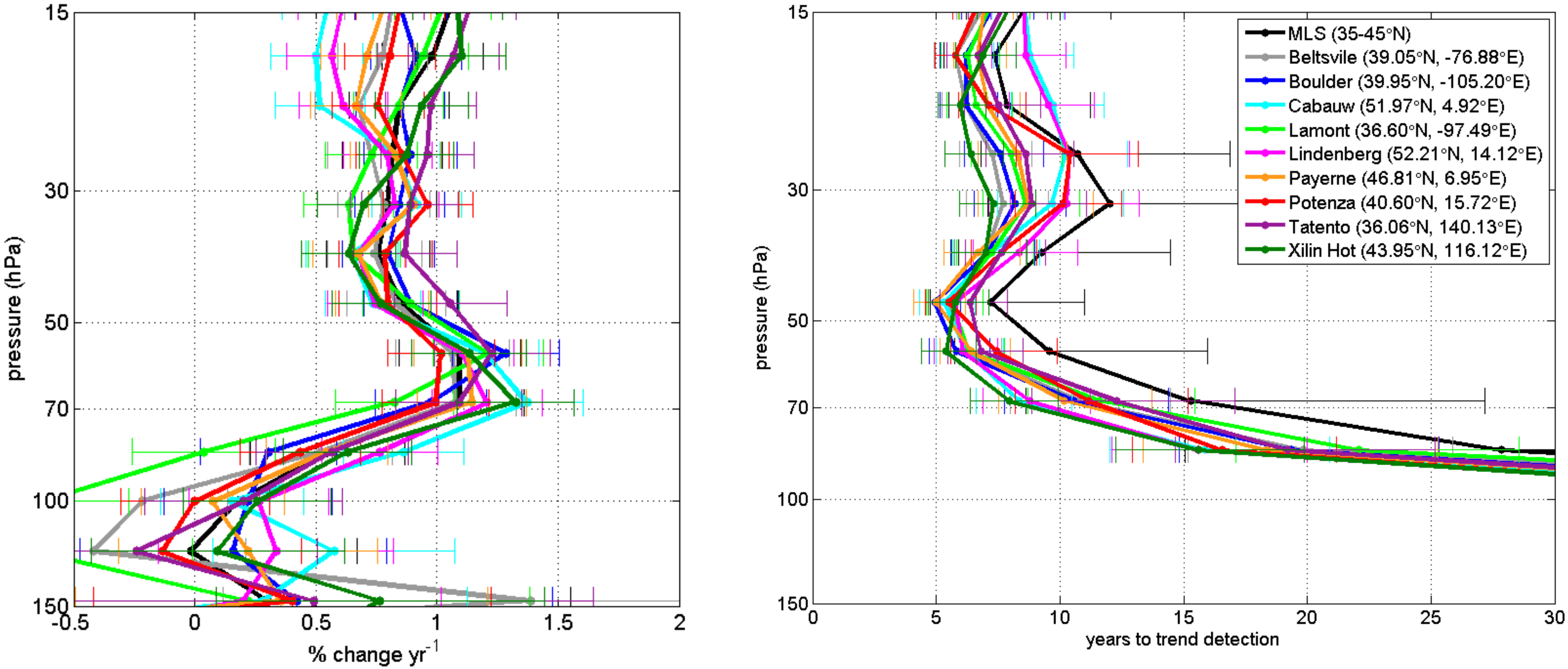
- Trends from linear fits of
  - the most recent 9 years of MLS and FPH data
  - the 30+ year Boulder record
- FPH and MLS in good agreement over the period 2004-2013

Time to detect trends (50 hPa @ Boulder)



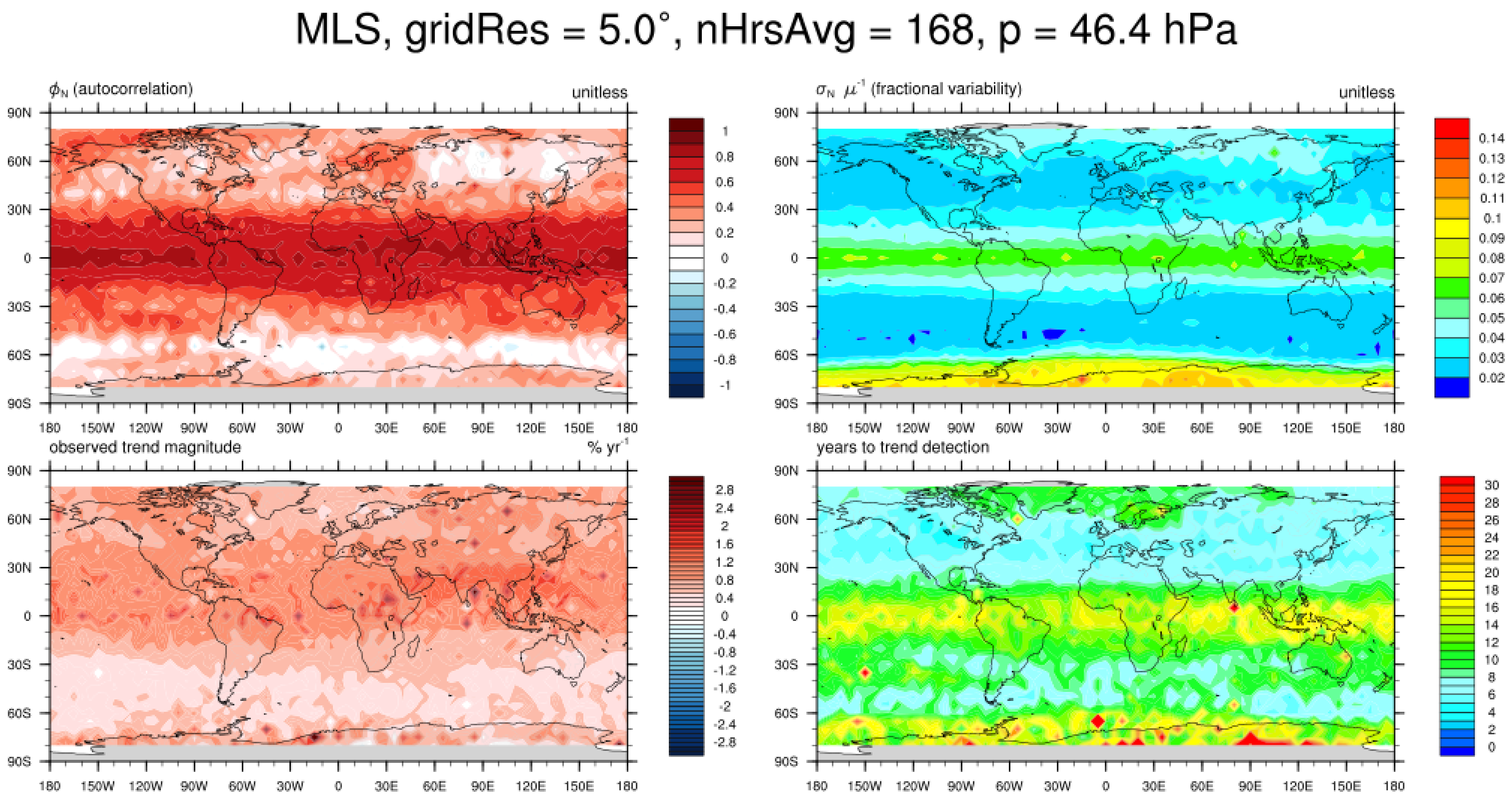
- Time to detect trends in LS for two scenarios
  - (left) autocorrelation, trend, variability from the 9 years (2004-2013) of MLS measurements
  - (right) autocorrelation, trend, variability from the 30+ year Boulder time

What about other GRUAN sites?

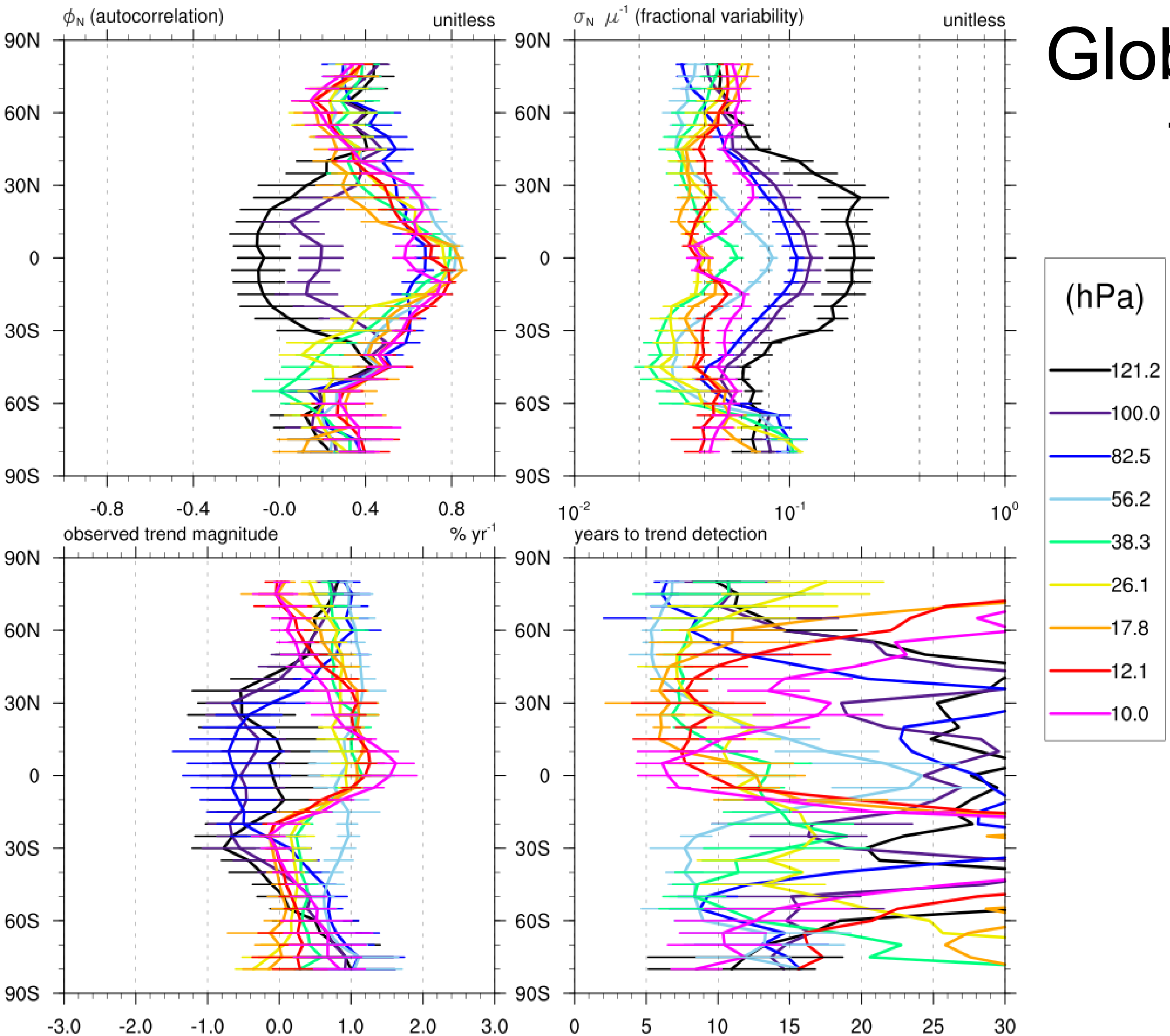


Using MLS 2004-2013 data, the trend patterns observed throughout the 35-45 degree zonal band are similar

Global maps at each pressure level



Global Summary from MLS
(2004-2013)



Raman lidar for trend detection water vapor : UT vs LS

Instrument	Frequency of operation	Years to detect UT trend	Years to detect 30+ yr LS trend	Years to detect 2004-2013 LS trend
MLS	1x/month	?	~10	~5
MLS	~1000x/month	?	~10	~5
FPH	1x/month	~30	~10	~5
ALVICE @ Table Mtn (5-10 hr/night)	7x/month	~18	~19*	~12
mini Raman lidar (1-2 hr/night)	7x/month	~20	NA	NA
ARM SGP Raman Lidar	All available monthly data			

Assumes all uncertainties in lidar data are random, therefore

Techniques must be used that tend to randomize sources of systematic uncertainty with total change kept to << 1%/yr

Systematic Uncertainties in RL Water Vapor Data Analysis

"It is assumed that the result of a measurement has been corrected for all recognized significant systematic effects and that every effort has been made to identify such effects."

Quantity	Frequency of significant occurrence	Magnitude of correction	Uncertainty in correction	Ancillary Data Required
Overlap	generally present	10% - 100x	~10%	radiosonde MR
temperature dependence	H2O filters less than 0.5 – 0.75 nm, N2 filters of 1-2 nm	0-7%	<1%	T profile, H2O Spectroscopy, filter transmission
molecular differential transmission	always present	~10%	<1%	density profile
particle differential transmission	Sometimes present for high-altitude lidar. generally present for low-altitude settings.	0-10%	<1%	aerosol extinction, optical depth
calibration	always present	~100x	~5-10%	radiosonde, MWR, GPS
signal-dependent bias	sometimes present due to fluorescence, leaky filters	~1 ppmv*	0.25 ppmv*	climatology or FP
pulse pileup	significant for photon counting only systems	up to 50%	0-5%	none

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How about those speculations from 2011?

- *Trend detection would be easier in the UT than LS*
  - FPH and MLS have lower random uncertainties in the LS than thought and the trends are larger than predicted by GEOS-5
    - Trend detection in LS more efficient
- *Raman water vapor lidar is better suited to UT trend detection than LS*
  - The relatively high random uncertainty of Raman lidar makes it much better suited to UT trend detection
  - Time to detect trends in UT will be fairly high for any instrument but also more tolerant of residual uncorrected systematic uncertainty than in the LS
  - Techniques are needed to randomize the systematic uncertainties that are corrected for in the data analysis

Summary and Conclusions - I

- Water vapor trends are currently being measured in the LS in 3-10 years with MLS and FPH
  - Low uncertainty measurements from FPH and MLS permit this
  - No instrument has yet been shown to be measuring trends in the upper troposphere
    - we conclude that trend detection of water vapor can be done more efficiently in the LS than UT
- For MLS and FPH there is little advantage to increasing the number of measurements per month for trend detection over the period 2004-2013
  - due to very high precision of MLS and FPH measurements and rapid increase in auto-correlation with wider temporal windows
- The 2004-2013 MLS data record indicates
  - trends and times to detect trends are similar throughout the 35-45 zonal band
  - mid-latitudes in both hemispheres attractive as sites for trend detection
  - stations arranged in other latitudes are needed although the tropics are less attractive.
- For any trend detection time series to be useful, recurring systematic uncertainties must be randomized to much better than 1% per year

Summary and Conclusions - II

- Future Work
  - continue study of current MLS/FPH based results
    - how to understand physically the relationships observed
  - analyze merged HALOE/MLS data record to look for similar pattern to the variability and autocorrelation
    - Does that record support
      - similar trends in 35-45 band
      - preferred geographic locations for siting stations
  - Submission to JGR
  - Quantify the trade-off between randomization of sources of systematic uncertainty in the Raman water vapor data analysis and the time to detect trend
    - propose techniques for accomplishing the needed randomization