Monitoring ILRS Barometric Accuracies using the Vienna Mapping Function for Optical Wavelengths

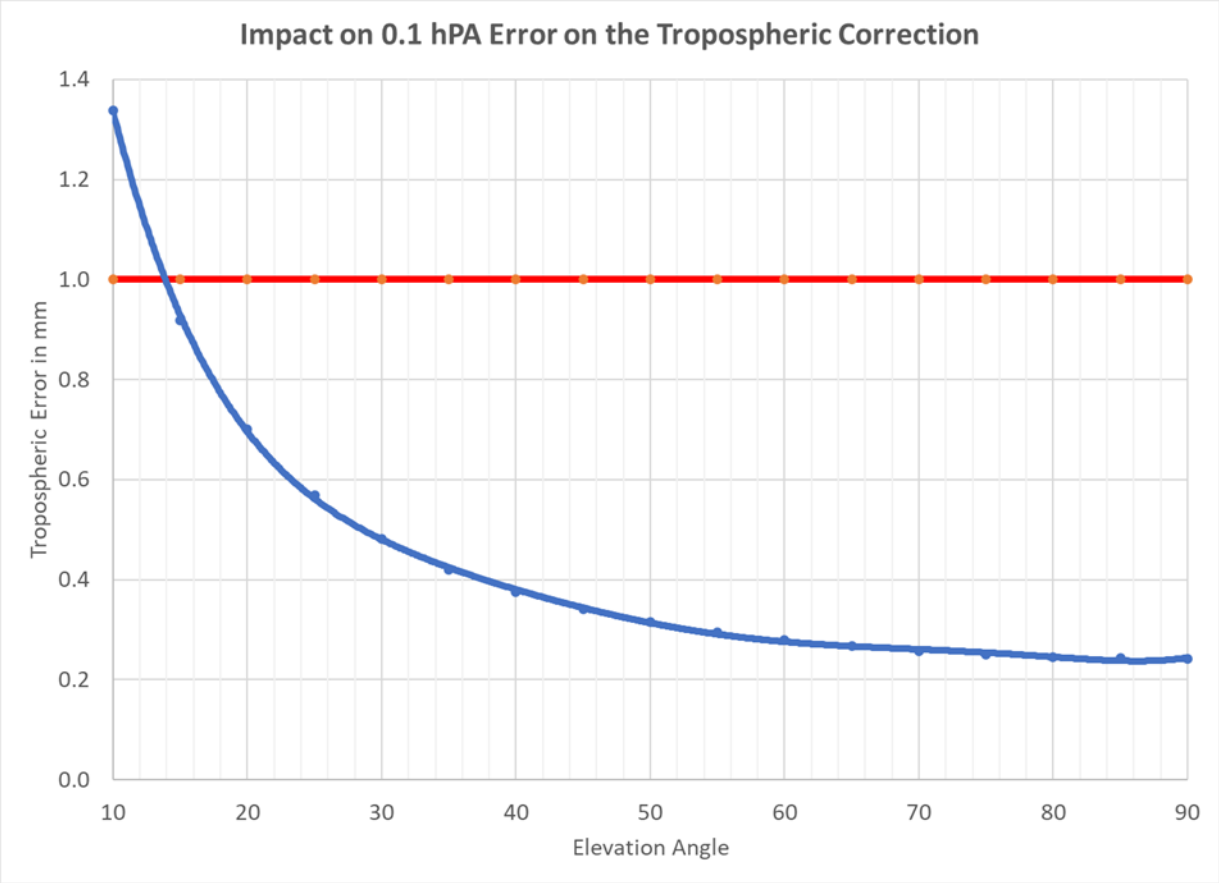
Van S. Husson

vhusson@peraton.com

Peraton/NASA SLR Operations Center

22nd International Workshop on Laser Ranging

SLR Error Signatures as a Function of Elevation

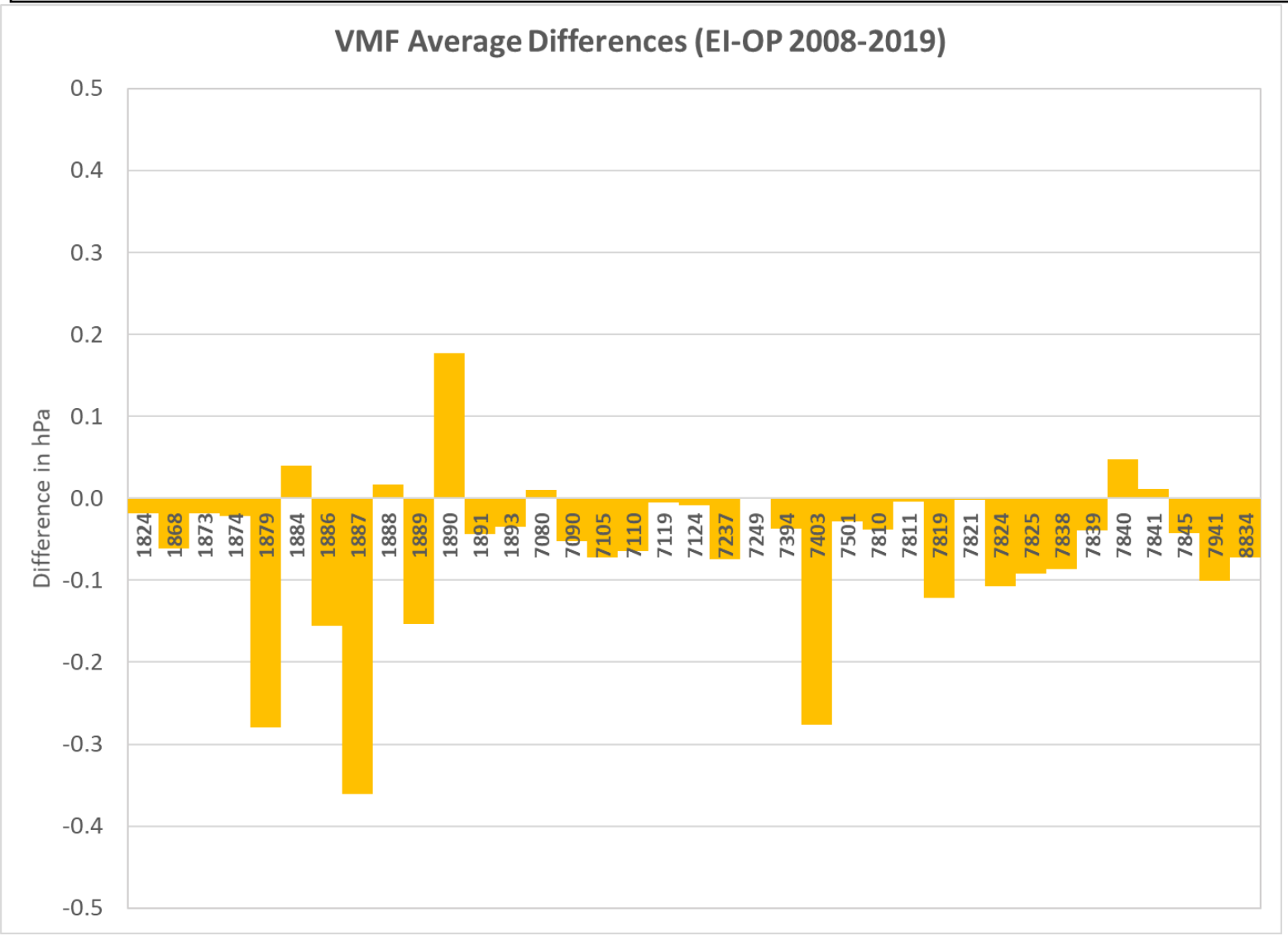


- Geodetic Global Observing System (GGOS) reference frame accuracy requirement is 1 mm and 0.1 mm/year stability [Pearlman, 2013].
- Based on these goals, the ILRS derived a requirement that all SLR components be calibrated to sub-mm accuracies [Prochazka, 2015]
- For tracking a satellite above 15 degrees, a pressure accuracy of 0.1 hPa will keep the systematic error below 1 mm.
- A barometric error will not impact data precision (single shot RMS, normal point RMS, calibration RMS) but will impact data accuracy.
- Solving for only a range bias will remove some but NOT all the systematic trends due to a tropospheric bias [Drożdżewski, 2021]. Unmodeled tropospheric biases will negatively impact station height.

Vienna Mapping Function (VMF)

- **VMF Reference: re3data.org: VMF Data Server; editing status 2020-12-14; re3data.org - Registry of Research Data Repositories. http://doi.org/10.17616/R3RD2H**
- **VMF data is available on the VMF Data Server at https://vmf.geo.tuwien.ac.at/trop_products/SLR/VMF3o/VMF3o_EI/ and VMF Data Server (tuwien.ac.at)**
  - VMF3o: the Vienna Mapping Functions for optical frequencies. Reference: VMF3o: the Vienna Mapping Functions for optical frequencies | SpringerLink
    - There are meteorological measurements every six hours for 186 unique SLR monuments. Some sites (e.g. Greenbelt, Wettzell) have more than one SLR monument.
    - There are semi-diurnal signals with amplitudes of a few millibars in pressure differences between the station's barometric measurements and the VMF
- **There are 3 flavors of VMF3o data**
  - VMF3o_EI: VMF3o parameters are based on ray-traced delays using European Centre for Medium-Range Weather Forecast (ECMWF) ERA-Interim Numerical Weather Models (NWM) data (a climate reanalysis). Time Span: January 1, 1990, to August 31, 2019.
  - VMF3o_FC: ECMWF forecasted NWM
  - VMF3o_OP: ECMWF operational NWM. Data is available next day. Time Span: January 1, 2008 to present.

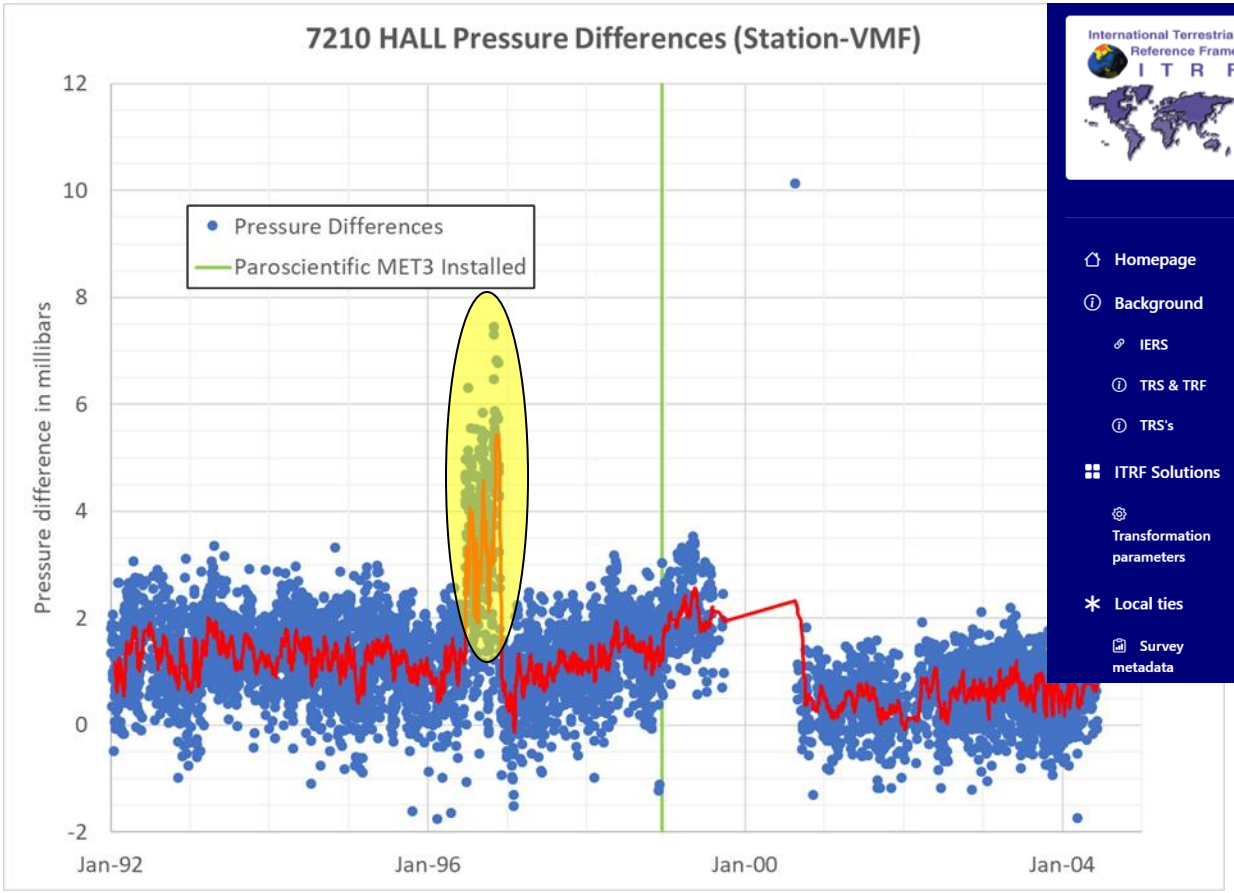
VMF System Characterization (EI versus OP)

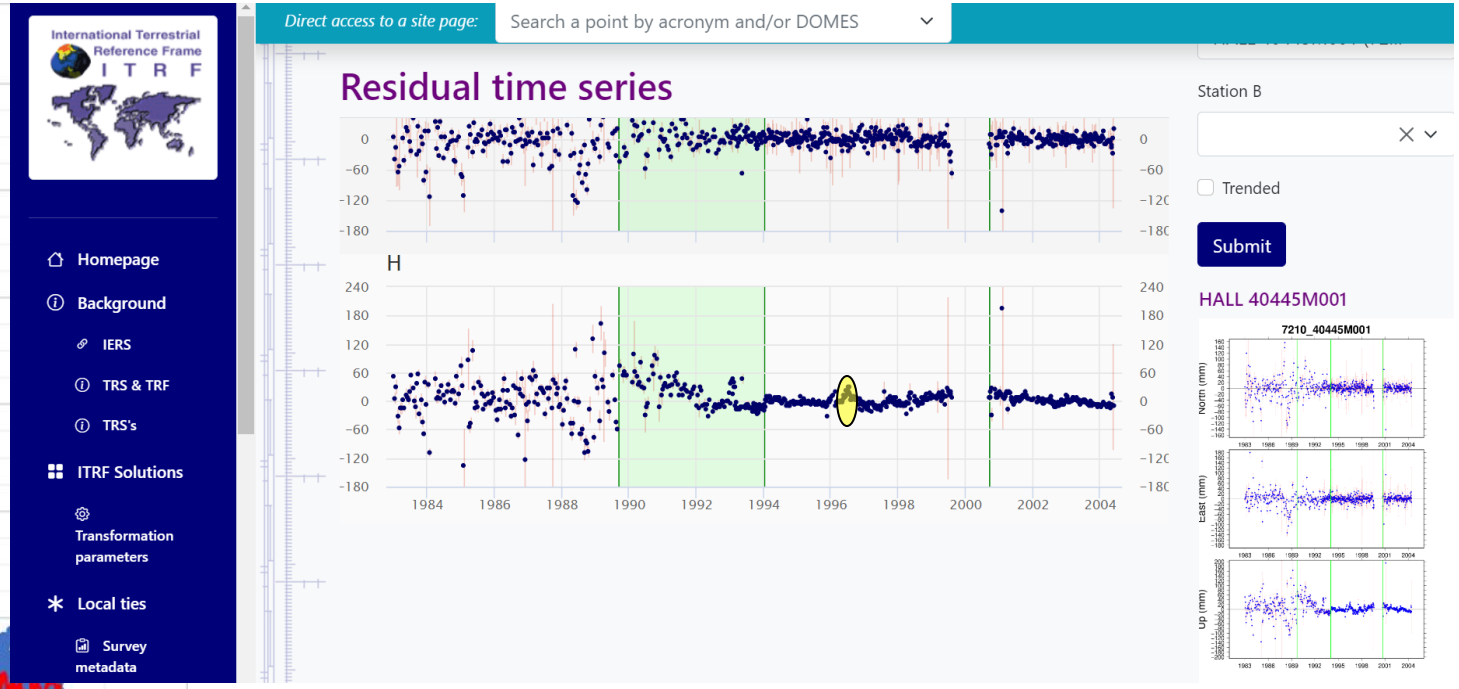


Mark	Location
1824	Golosiiv, Russia
1868	Komsomolsk-na-Amure, Russia
1873	Simeiz, Ukraine
1874	Mendeleevo, Russia
1879	Altay, Russia
1884	Riga, Latvia
1886	Arkhyz, Russia
1887	Baikonur, Kazakhstan
1888	Svetloe, Russia
1889	Zelenchukskya, Russia
1890	Badary, Russia
1891	Irkutsk, Russia
1893	Katzively, Ukraine
7080	McDonald, TX, USA
7090	Yarragadee, Australia
7105	Greenbelt, MD, USA
7110	Monument Peak, CA, USA
7119	Haleakala, HI, USA
7124	Tahiti, French Polynesia
7237	Changchun, China
7249	Bejing, China
7394	Sejong City, Republic of Korea
7403	Arequipa, Peru
7501	Hartebeesthoek, South Africa
7810	Zimmerwald, Switzerland
7811	Borowiec, Poland
7819	Kunming, China
7821	Shanghai, China
7824	San Fernando, Spain
7825	Mt Stromlo, Australia
7838	Simosato, Japan
7839	Graz, Austria
7840	Herstmonceux, United Kingdom
7841	Potsdam, Germany
7845	Grasse, France
7941	Matera, Italy
8834	Wettzell, Germany

- The mean difference between VMF3oEI and VMF3oOP for all 186 SLR monuments for the 12 years is minus 0.07 hPa (EI-OP).
- Listed here are most of the current active sites.

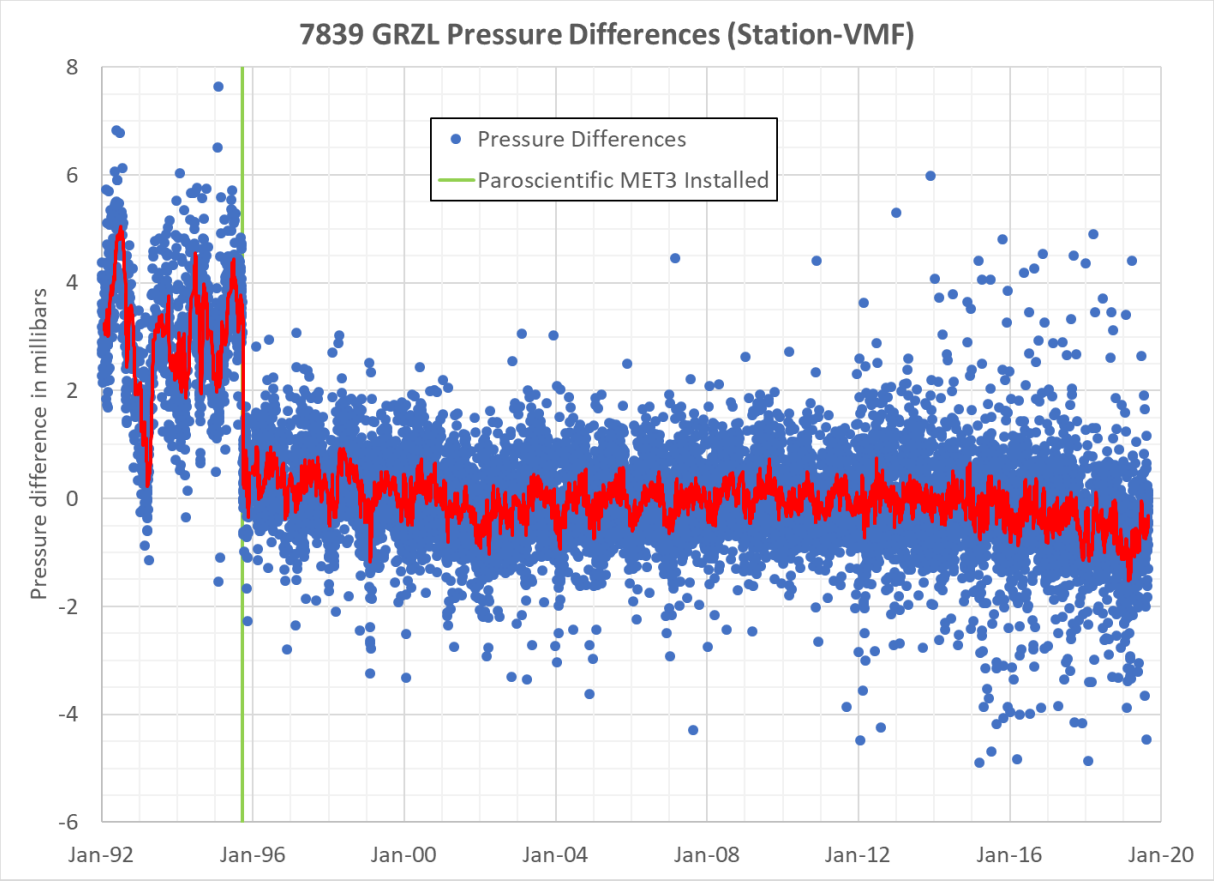
7210 HALL Pressure Analysis
Impact of an Unmodeled Tropospheric Bias

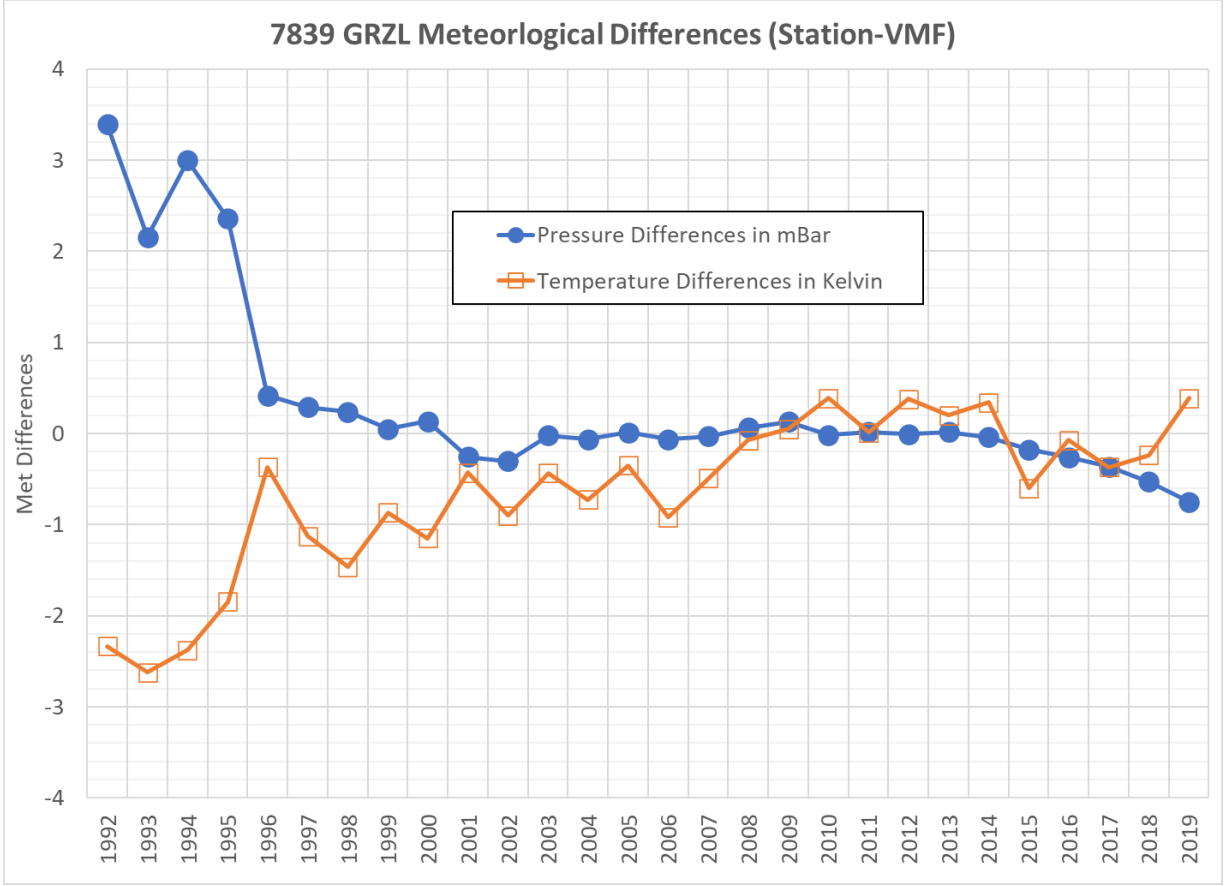




- **The highlighted area on the left chart indicates a sudden jump in the HALL (7210) barometric pressures of few hPa. The highlighted area on the right chart indicates the HALL (7210) ITRF2020 height residuals [Altamimi, 2022] for this same period**

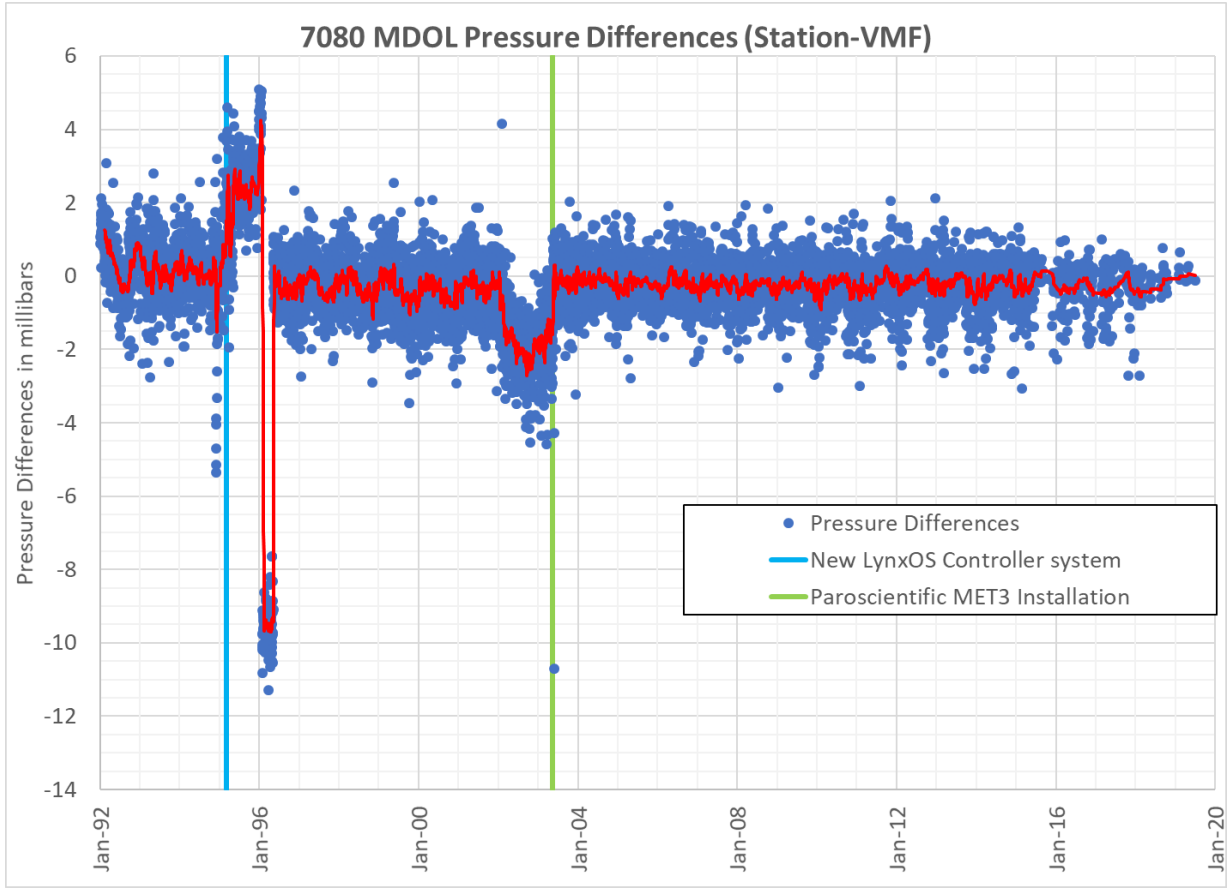
7839 GRZL Pressure Analysis

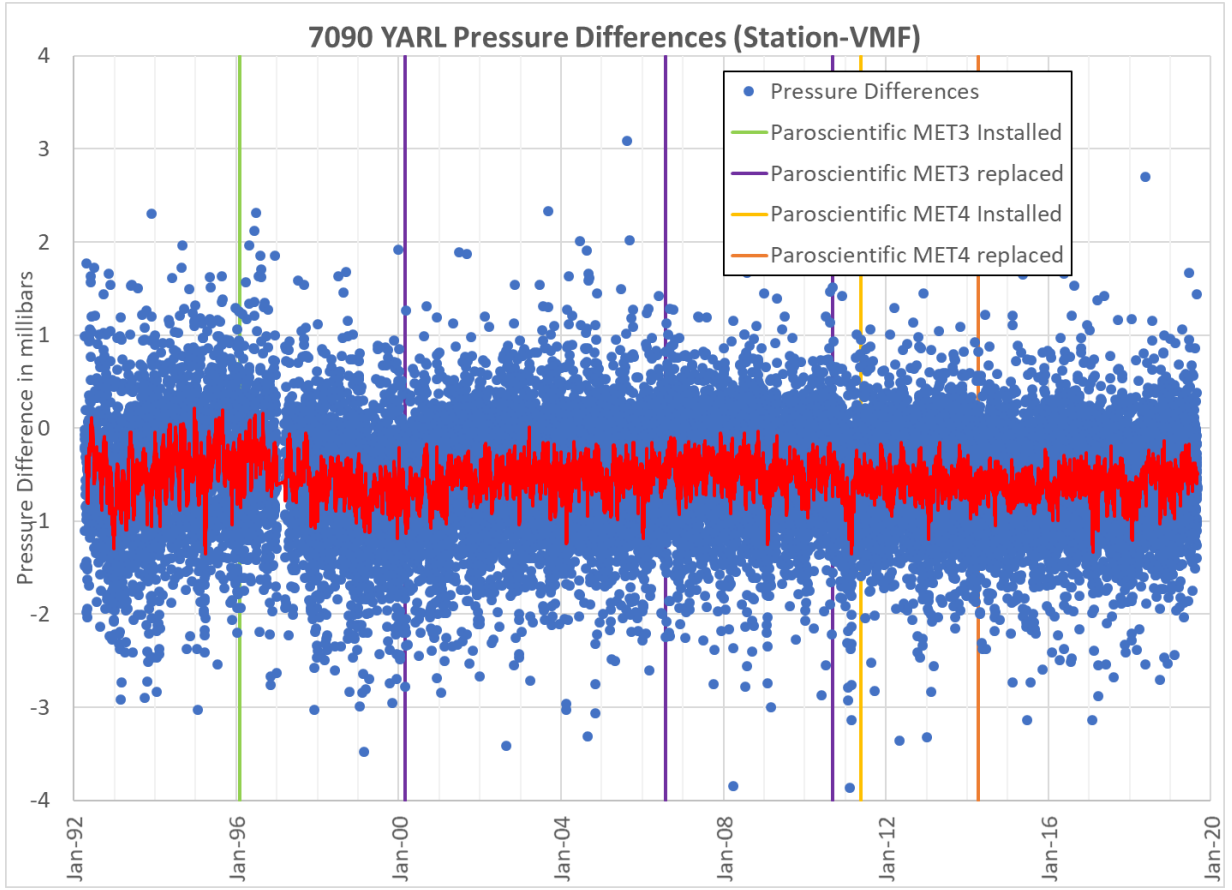




- Left chart: pressure differences (Station-VMF3oEI) aggregated every 6 hours. Red line a 20-point running average.
- There is discontinuity when the Paroscientific MET3 was installed on 22-Sep-1995.
- Right chart: pressure and temperature differences (Station-VMF3oEI) aggregated yearly.
- *Note: All Graz pressures are from the original data release(release 0). In 2015, the MET3 began to drift -0.13 mbars/year.*

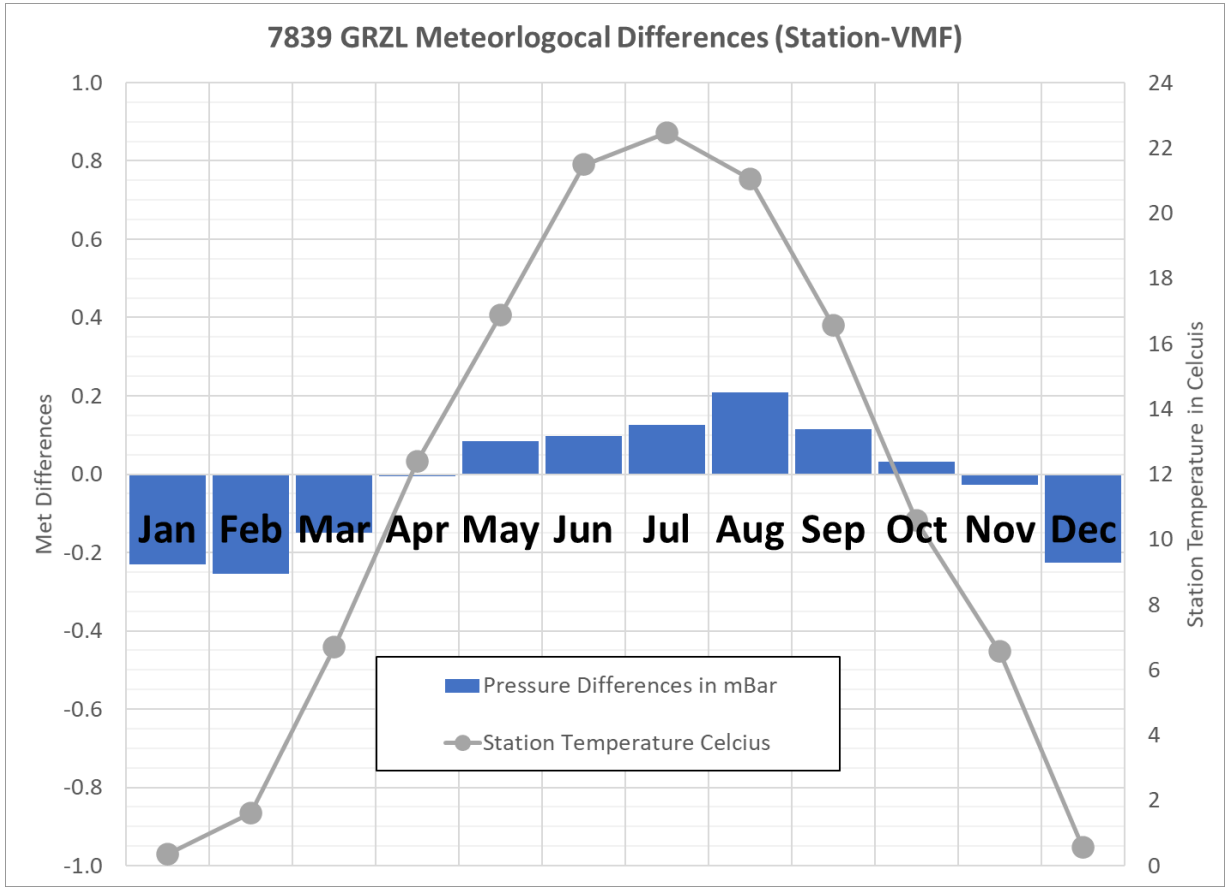
7080 and 7090 Pressure Analysis

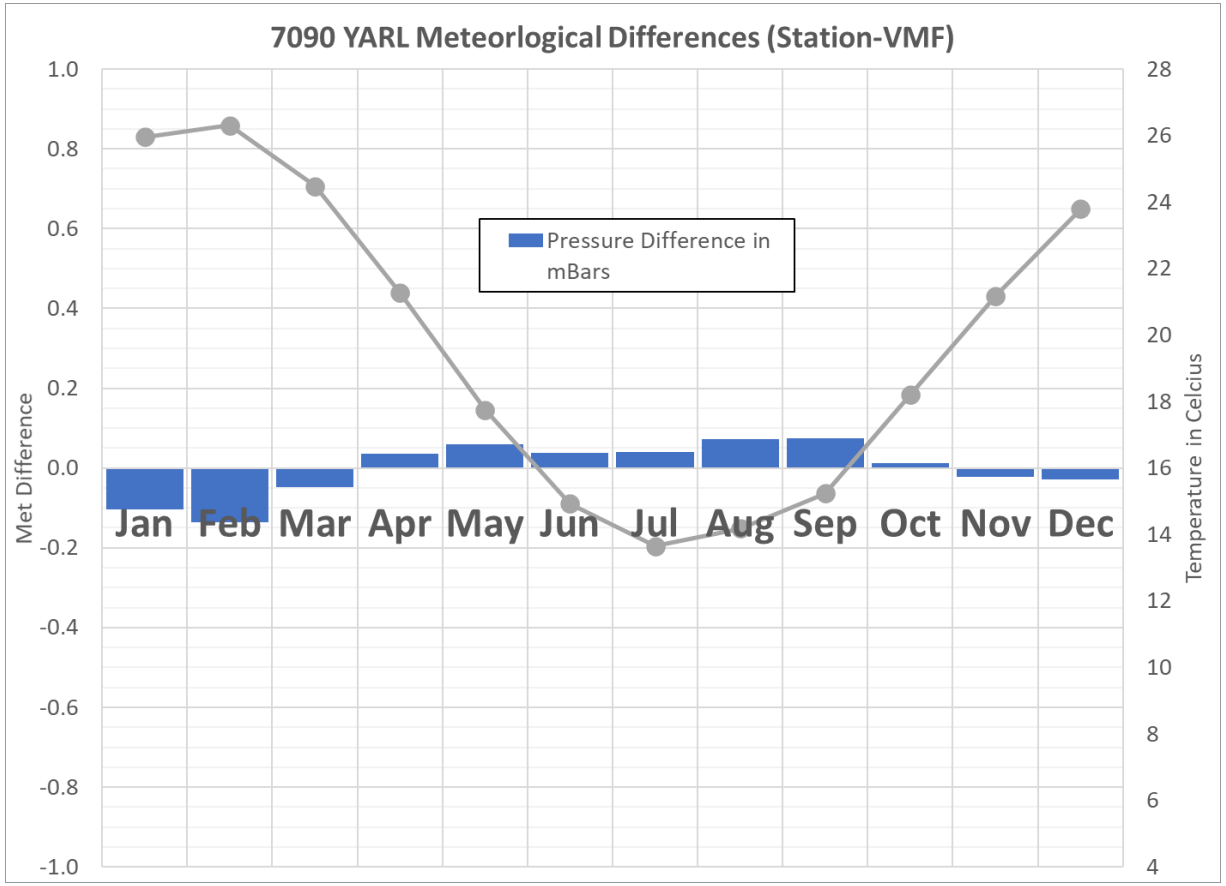




- There are three abrupt discontinuities in the 7080 barometric measurements. Replacing the Setra barometer with Paroscientific MET3 eliminated the discontinuities.
- There is -0.54 millibar offset between the Station 7090 and the VMF. Based on the left chart the 7090 meteorological sensors were calibrated/replaced every few years. Which data is more accurate?

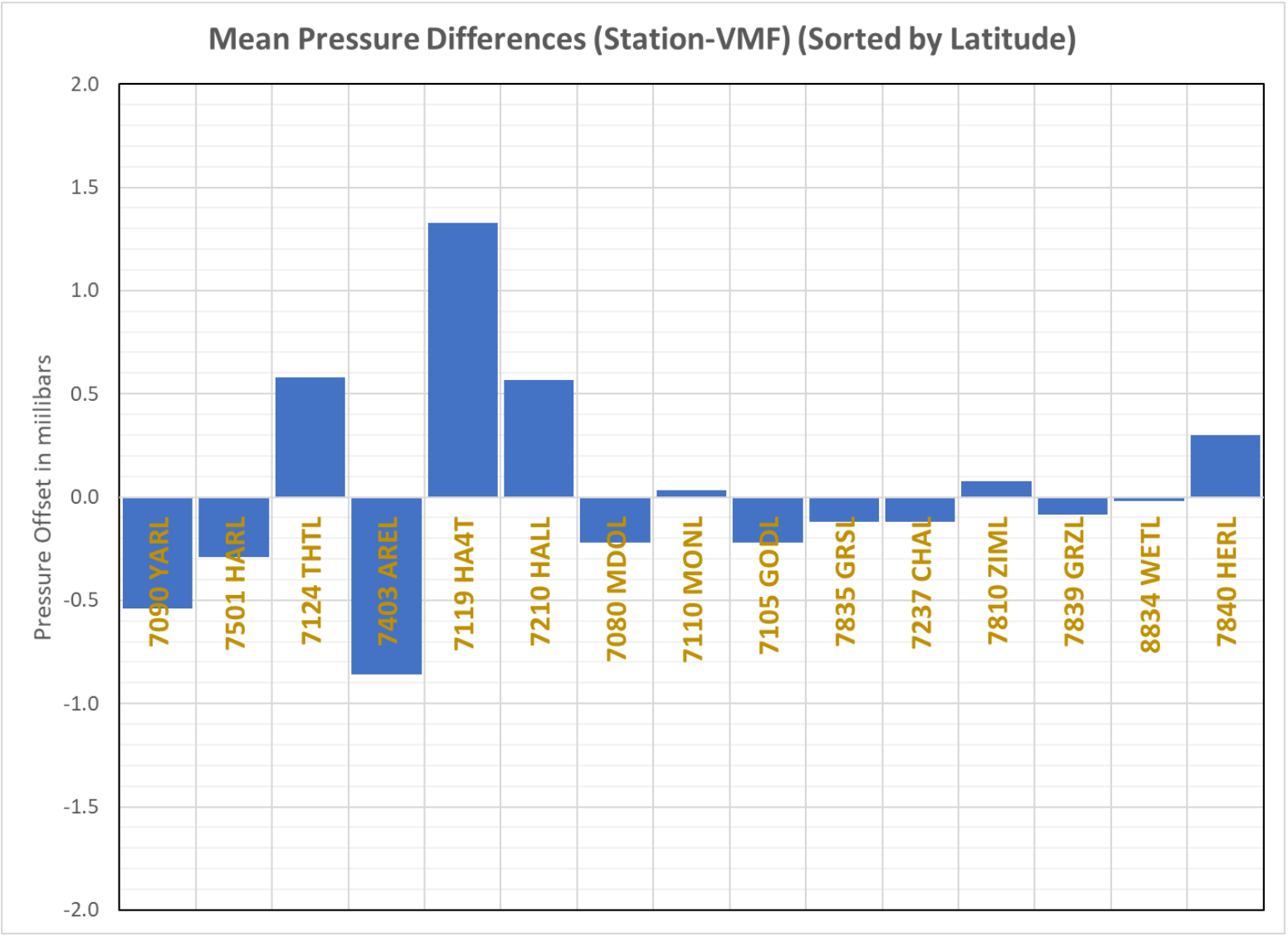
Seasonal Pressure Variations (Station – VMF)





- Here are 7839 and 7090 Seasonal Pressure Variations (Station – VMF). Pressure differences are on the left axes and the site temperature is on the right axes.
- Are these seasonal variations in the VMF; in our barometers; or a combination?

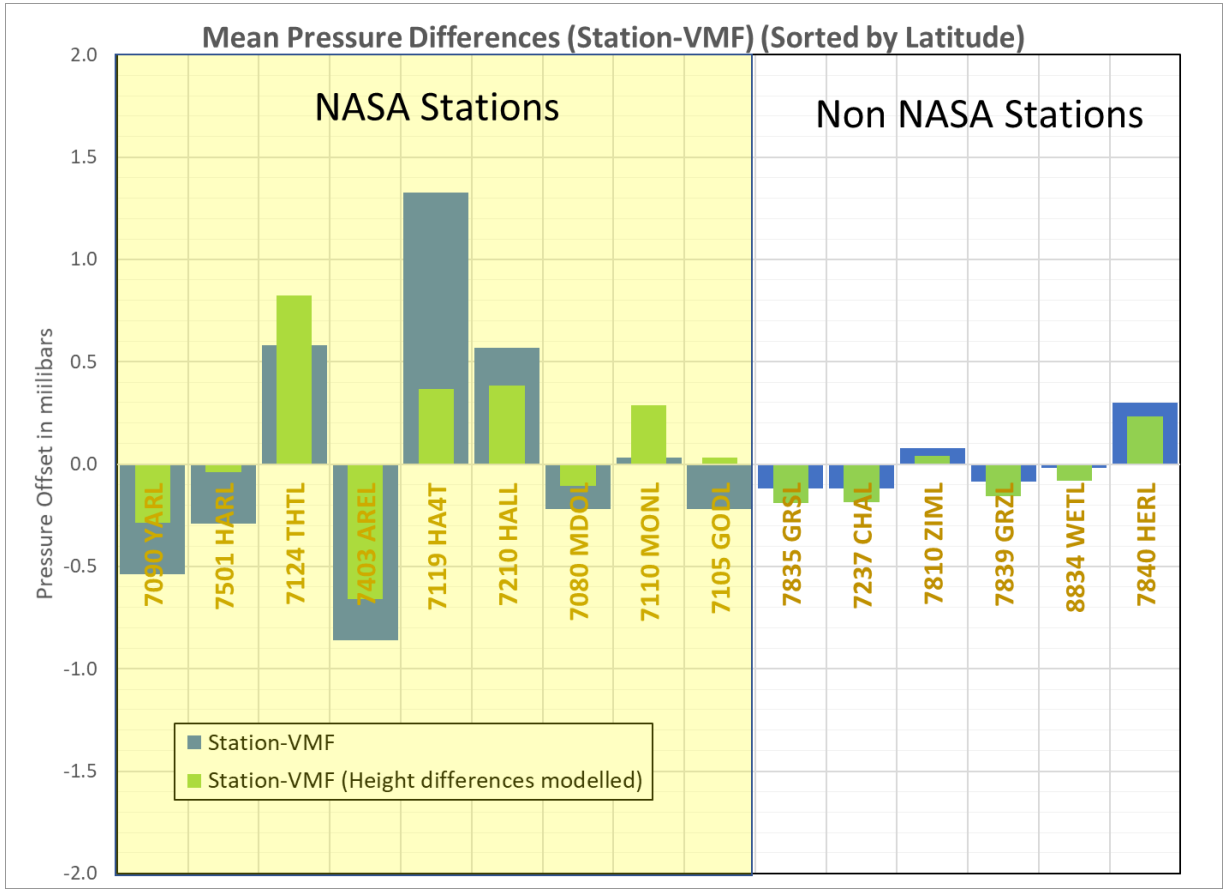
Mean Pressure Differences (Station-VMF) Summary



- **These are the mean pressure differences when the differences appear relatively stable between the site's measurements and the VMF.**
- **Potential errors sources are:**
  - The barometric sensor
  - Ray-Tracing
  - The station height used in the VMF
  - Unmodeled height errors between the barometric sensor and the system reference point
- **Reducing barometric systematic errors to the sub-mm level requires absolute pressure accuracies of 0.10 to 0.15 millibars**
- **Station heights in the VMF need to be accurate to better than 1 meter to keep the uncertainty in the barometric pressure to less than 0.1 millibars**

VMF and SRP Height Differences and Mean Pressure Differences

Station Type	Station	Latitude	VMF-Station SRP Height (m)
NASA	7090 YARL	-29.046	-2.516
NASA	7501 HARL	-25.890	-2.507
NASA	7124 THTL	-17.577	-2.429
NASA	7403 AREL	-16.466	-2.000
NASA	7119 HA4T	20.706	9.609
NASA	7210 HALL	20.707	-0.159
NASA	7080 MDOL	30.680	-1.140
NASA	7110 MONL	32.892	-2.517
NASA	7105 GODL	39.021	-2.521
Non-NASA	7835 GRSL	43.755	0.676
Non-NASA	7237 CHAL	43.791	0.669
Non-NASA	7810 ZIML	46.877	0.368
Non-NASA	7839 GRZL	47.068	0.714
Non-NASA	8834 WETL	49.144	0.621
Non-NASA	7840 HERL	50.867	0.700

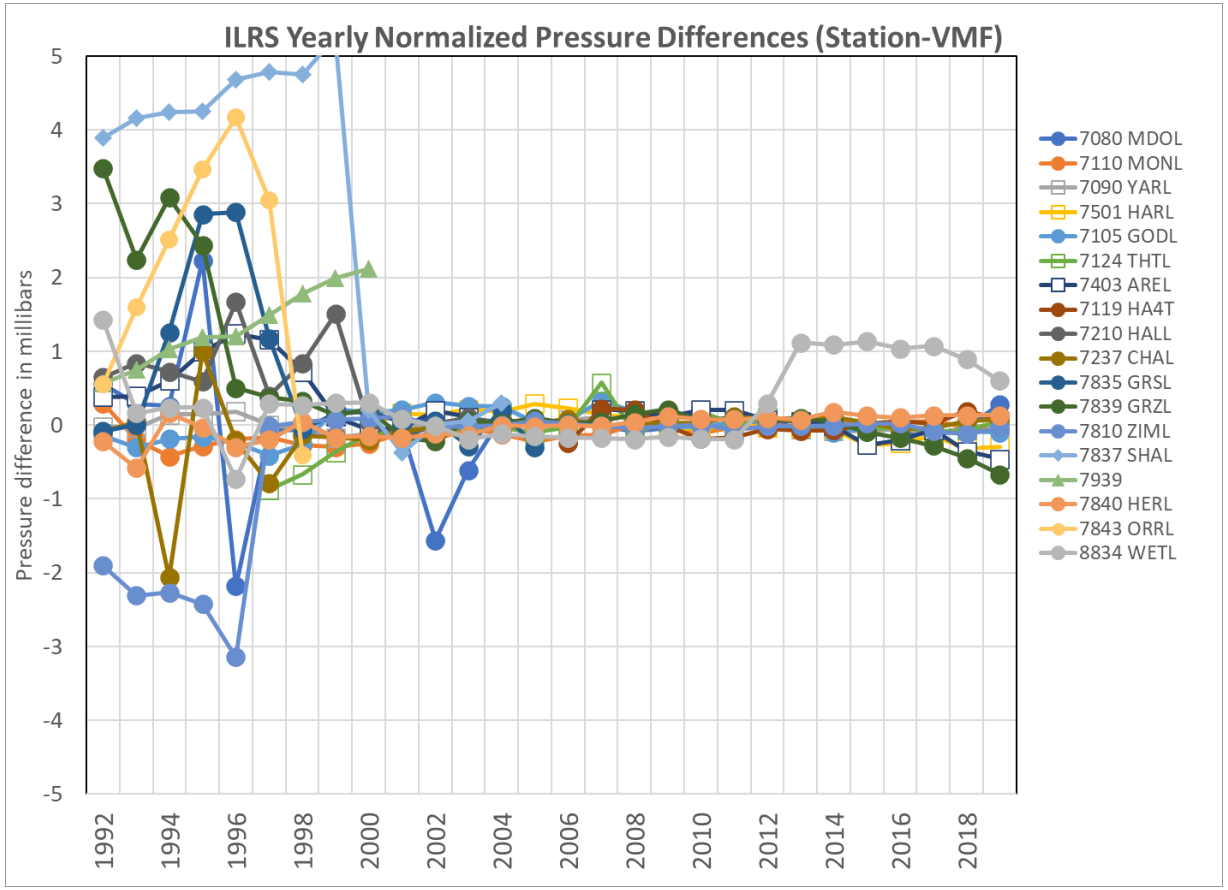


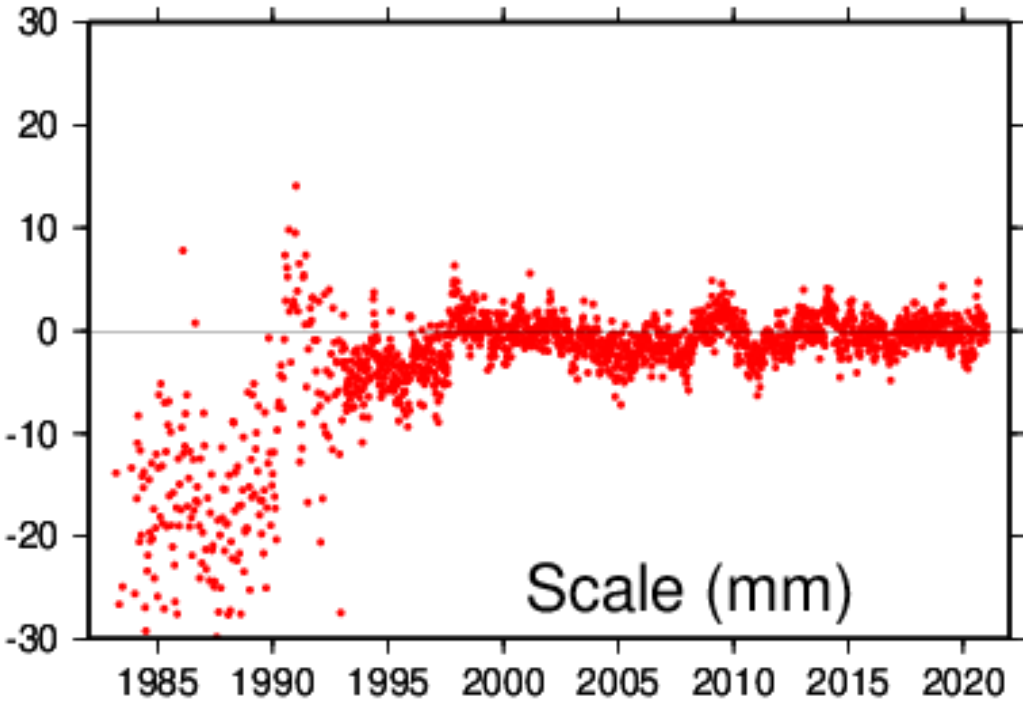
- The VMF station heights are based on approximate heights from the ILRS site eccentricity file.
- For NASA systems, the VMF heights are based on the monument and NOT the system reference point.

Notable Height Differences between the SRP and the Barometric Sensor

Mark	Location	Height Difference (m)	Modelled Onsite
1824	Golosiiv, Russia	-2.5	?
1893	Katzively, Ukraine	-3.5	?
7210	Haleakala, HI, USA	2	No
7249	Bejing, China	-1.2	?
7810	Zimmerwald, Switzerland	2	?
7824	San Fernando, Spain	12	?
7821	Shanghai, China	2	?
7835	Grasse, France	2.5	?
7836	Potsdam, Germany	-2.28	?
7837	Shanghai, China	2	?
7838	Simosato, Japan	-3	Yes
7841	Potsdam, Germany	-5.2	?
7941	Matera, Italy	2	Yes
8834	Wettzell, Germany	9.4	Yes

ILRS Yearly Normalized Pressure Differences and ITRF SLR Scale





- As more accurate barometric sensors were installed at each site during the mid to late 1990's, the yearly barometric offsets stabilized which had a positive impact on SLR scale.

Summary/Recommendations

- VMF3o System Characterization
  - There are systematic differences between VMF3oEI and VMF3oOP that are site-specific. When averaged over 12 years, these VMF differences for all sites are all less +/- 0.4 hPa.
  - VMF3o uses approximates heights from the ILRS system eccentricity file. But any errors in the VMF SRP heights can be accurately modelled.
  - After modeling any VMF3o SRP height errors, there are still site-specific systematic differences between VMF3oEI and the SLR barometric pressures up to a few tenths of hPa.
- The VMF3o data can detect drifts and discontinuities in the SLR barometers and can be used to model historical barometric errors
- The proliferation of more accurate SLR meteorological sensors in the mid to late 1990's had a positive impact on our SLR data quality and SLR scale.
- **Station Recommendations**
  - Perform yearly barometric calibrations with a known standard and report results in your station history log
  - In Section 12.01 Additional Information of your site log, if the height difference between your barometric sensor and intersection of optical axes is not zero, document any adjustments made to your barometric measurements to account for the height difference