EXTERNAL

ADQCC – EMIRATES METROLOGY INSTITUTE (EMI)

Measurement of Local Gravity for Force, Torque and Pressure Standards - Good enough for the requirements expected in 2050?

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مجلس أبوظبي للجودة والمطابقة
ABU DHABI QUALITY AND CONFORMITY COUNCIL

EMI laboratories are located in the CERT Health Science Building

Facilities

Location

- Health Science Building, located at the CERT Technology Park, was converted to house the EMI laboratories
- A net area of over 1 200 m^2 of the ground floor of the two-floor building is used for 8 separate laboratories, a conference room, office area for 34 staff members, and a receipt and dispatch area
- Calibration laboratories have environmental control in accordance with international recommendations - 24/7 humidity and temperature control (±0.2 °C for the most demanding laboratories)

Basic Equations

Force: $F = m \times g \times \left(1 - \frac{\rho_a}{\rho_m}\right)$

Torque: $T = F \times d$

Pressure: $P = \frac{F + (D \times \tau)}{A} + P_{ref}$

and

$$A = A_0 \times \left[1 + (t - t_0) \times \left(\alpha_{pist} + \alpha_{cyl}\right)\right] \times \left[1 + \lambda \times \left(P - P_{ref}\right)\right]$$

1000 N·m Torque Standard Machine

7 MPa Gas Pressure Standard

Calculation of Local Gravity - g

(1) $$g = 9.780\,327 \times (1 + 0.005\,3024\,sin^2\emptyset - 0.000\,0058\,sin^2 2\emptyset) - 3.088 \times 10^{-6} \times H \quad \mathrm{m/s^2}$$

Calculation nearly always gives results within 1 x 10^{-3} m/s^2

(2) PTB website: www.ptb.de/cartoweb3/SISproject.php

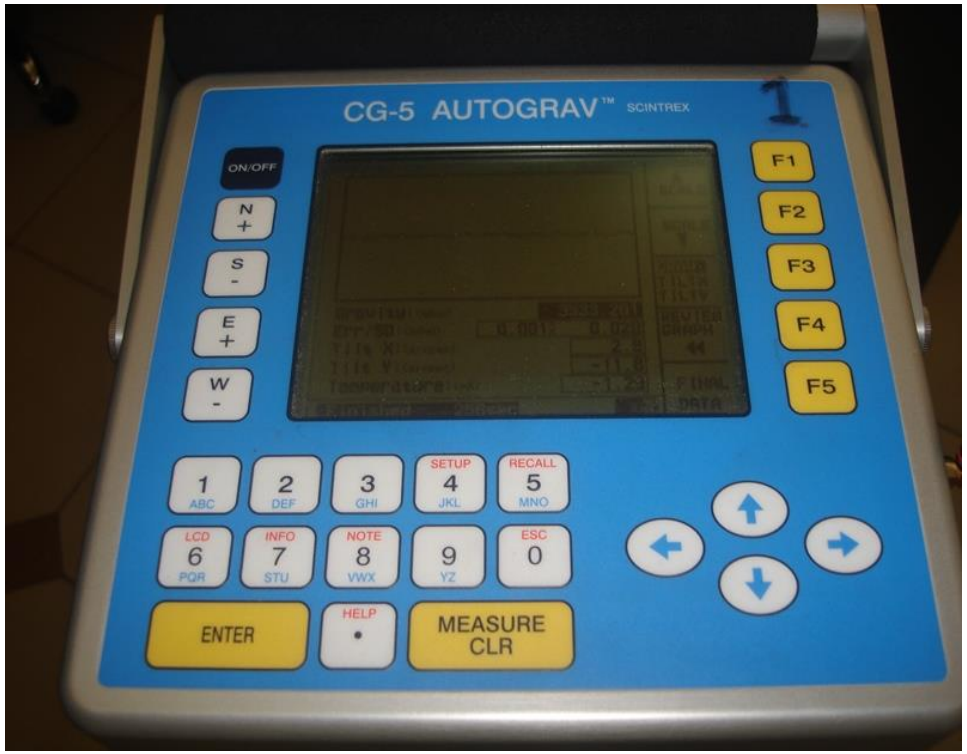
For 8 out of 10 UAE reference locations, the difference between the known reference value and the calculated value was greater than the uncertainty given for the calculation, but results better than 5 x 10^{-4} m/s^2

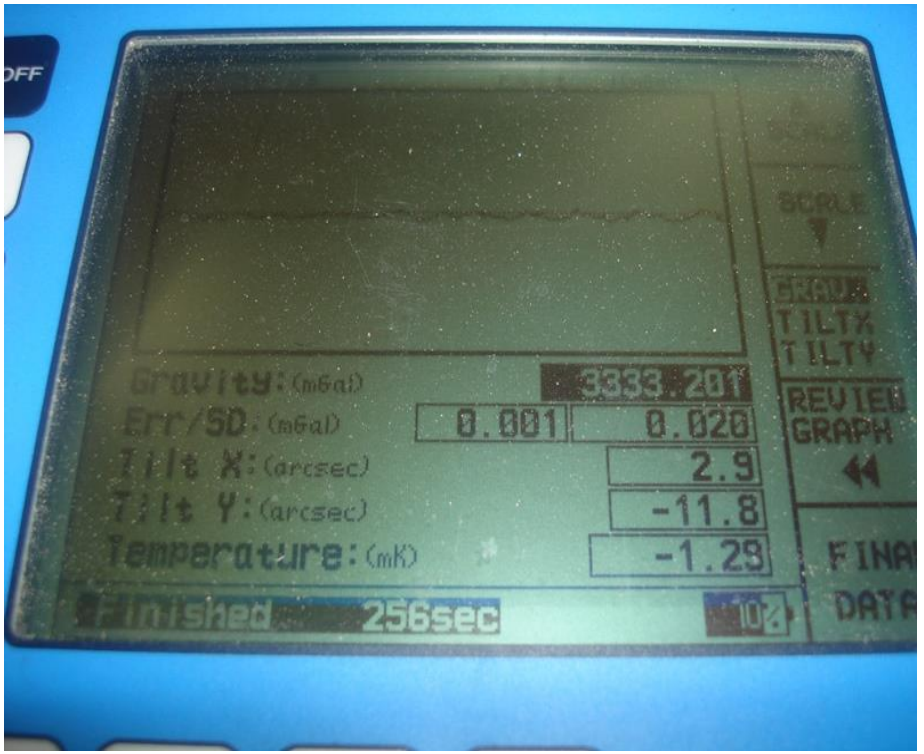
Neither method gives sufficiently low uncertainty

Measurement of Local Gravity - g

- Use of commercially-available absolute gravity meter considered, but cost prohibitive and none available for hire in UAE. Also difficult to use
- Two CG-5 gravity meters capable of gravity comparison measurements provided by the Abu Dhabi Petroleum Institute (PI) under contract to EMI
- Gravity meters have excellent performance and inbuilt compensation for important effects:
  - Resolution of 1µGal (10^{-9} g)
  - Repeatability better than 5 µGal
  - Wide operating temperature range - up to 55 °C external temperature
  - In-built temperature compensation with resolution of 0.01 mK
  - In-built X & Y tilt compensation with resolution of 0.1 arcsecond
  - In-built GPS to provide location and time of measurement, giving option of automatic correction for Earth tides

Portable Gravity Comparison Meter





Two CG-5 gravity meters provided by the Abu Dhabi Petroleum Institute

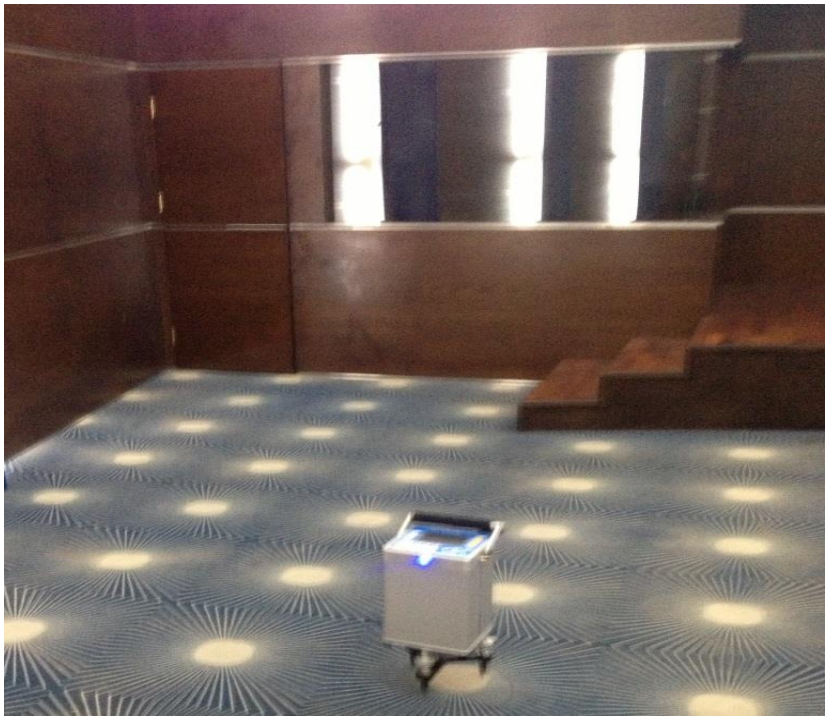
Measurement Protocol

(Ref) (Abs) (EMI1) (EMI2) (Ref)

Above measurement cycle of five stations was repeated over three consecutive days, using the same *Ref* location at the Petroleum Institute, but a different *Abs* station each day

***Abs* Station**	**Location**	***g***	**Uncertainty (k=1)**
		mGal	mGal
1	Nazwa	978 846.767	0.004
2	Hatta	978 881.266	0.005
3	Al Ain	978 768.517	0.006

Measurement Locations

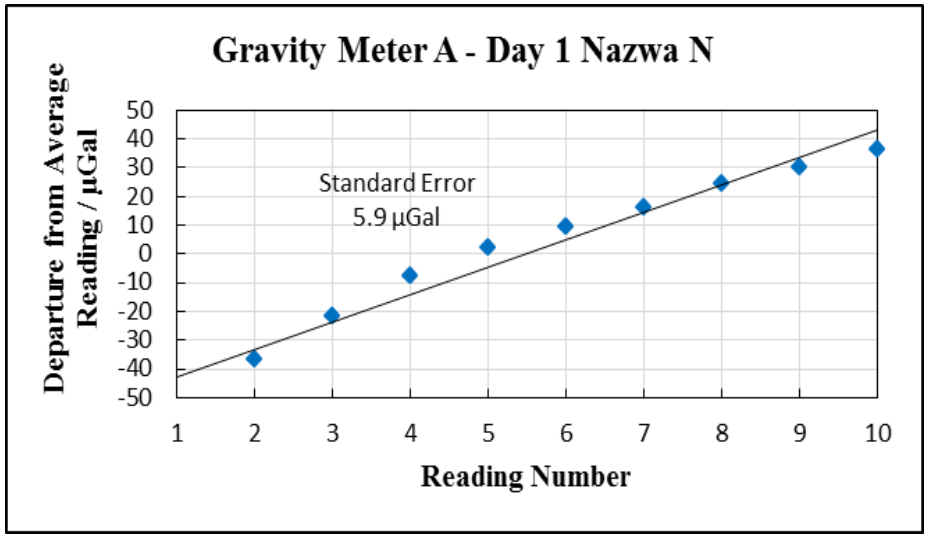


EMI2

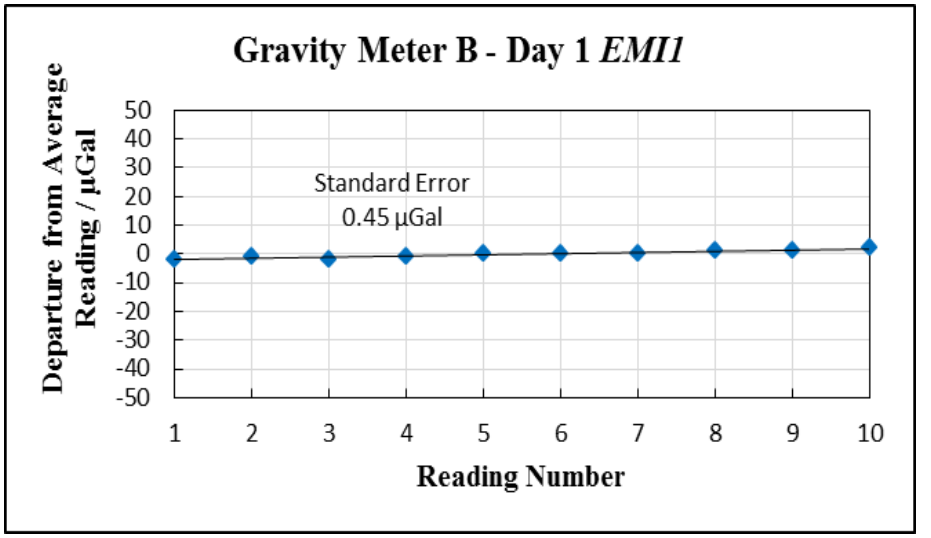
Nazwa

Performance of the Gravity Meters over a Measurement Period of 42 min 40 s

Worst Case

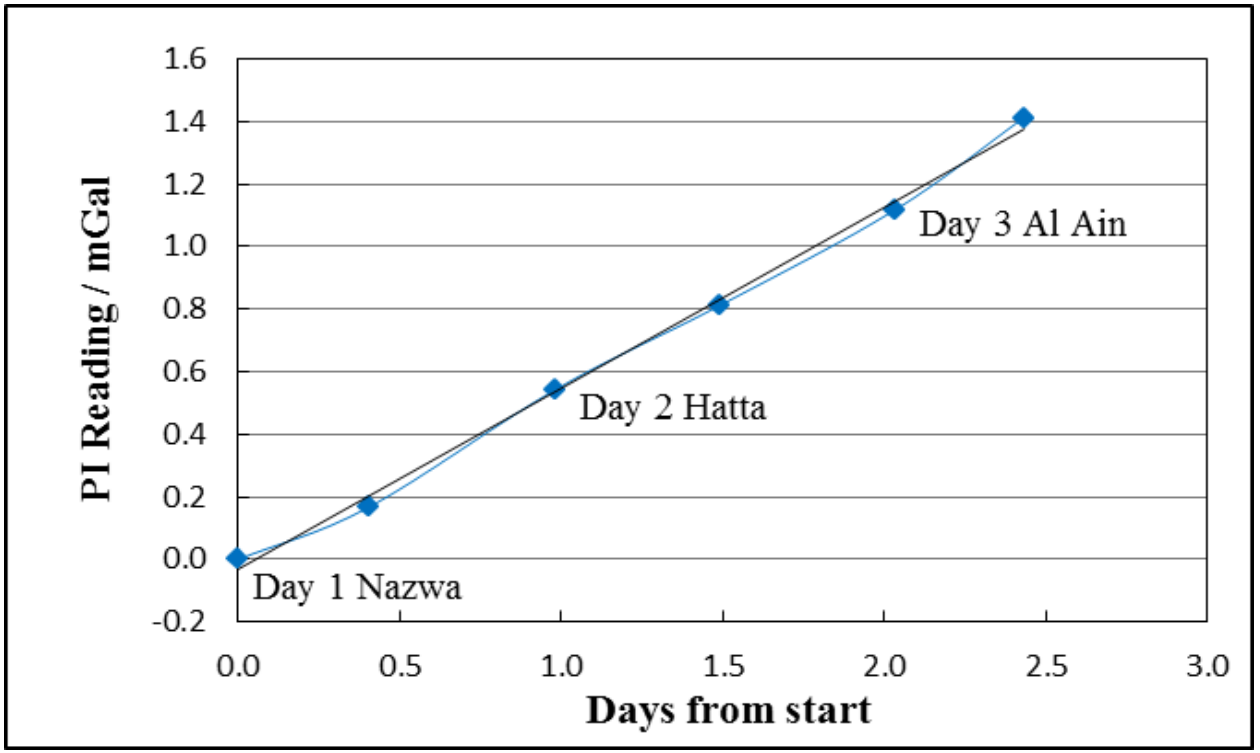


Best Case



RMS of all the Standard Errors is 2.8 µGal and 1.2 µGal for Gravity Meters A and B, respectively

Drift of Gravity Meter A



Standard error for the fit is 0.034 mGal

All results corrected for the drift of the gravity meters

Average results obtained at the EMI locations

Location	Meter	Nazwa	Hatta	Al Ain
		Measured value of g / mGal		
EMI1	A	978 888.047	978 888.077	978 888.099
	B	978 888.049	978 888.091	978 888.123
EMI2	A	978 888.067	978 888.097	978 888.120
	B	978 888.069	978 888.111	978 888.143

Measurement results at floor level at the two EMI locations

Estimated uncertainty (k=2) for all values is 0.16 mGal

Average results at the working levels at EMI

Location	Value of g	Uncertainty (k=2)	
	m/s^2	m/s^2	relative
EMI1 (Pressure Laboratory) 1.115 m	9.788 877 3	0.000 002 0	2.0×10^{-7}
EMI2 (Torque Laboratory) 0.450 m	9.788 879 6	0.000 002 0	2.0×10^{-7}

Uncertainty increased because average value used for all weights in the stacks

Measurement Uncertainty

Uncertainty Contributor	Contribution (k=1) µGal	Note
Resolution	0.3	Insignificant
Short-term repeatability	2.0	Small - based on 10 measurements
Drift over 3 days	**34.0**	**Significant Type A contribution**
Scale error	**1.0 - 72.0**	**Significant - from 3 absolute stations**
Value at *Abs* station	4.0 - 6.0	Small
Location (X and Y)	2.0	Small - well controlled
Elevation at measurement (Z)	1.7 -8.7	Small - well controlled
Tilt	3.0	Small
Earth tide	**61.2**	**No correction for Earth tide applied**
Air pressure	2.9	Small
Water level	8.2	Small
Polar motion	2.4	Small
Elevation at working location	**54.6**	**Average taken for all weights in stack**
Inter-mass gravity force	7.0	Small

Calculation of Air Density

- CIPM-2007 method gives best calculation for air density - Metrologia, 45 (2008), pages 149 to 155

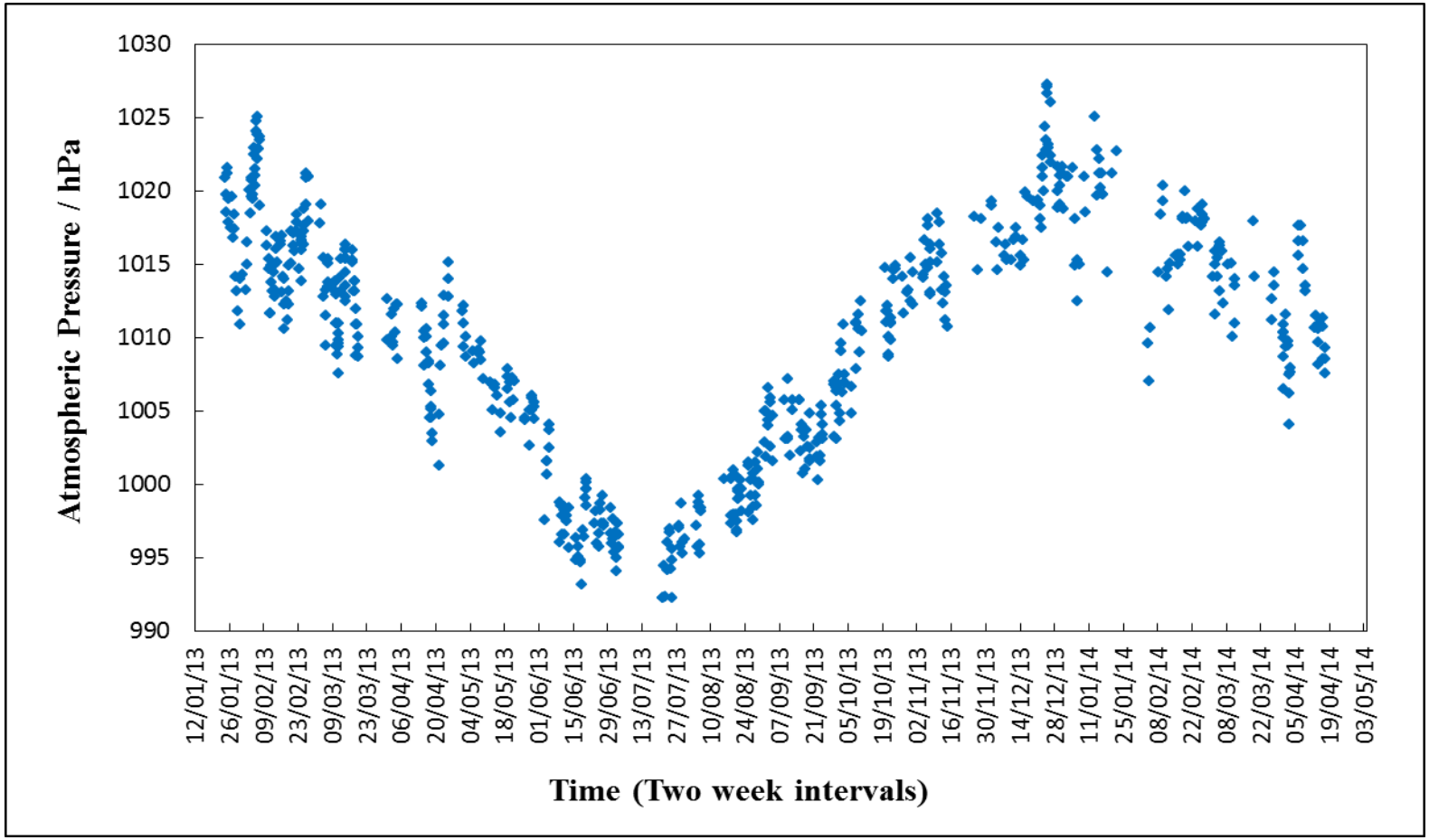
doi 10.1088/0026-1394/45/2/004

- Annex E.3 of OIML R 111-1, 2014(E) gives easier to use method:

$$\rho_a = \frac{0.34848 \times P - 0.009 \times RH \times e^{0.061 \times t}}{273.15 + t}$$

For EMI conditions, calculation agrees with CIPM 2007 method within a relative value of 2 x 10^{-4}, which is equivalent to a relative difference in F of only 30 x 10^{-9}

Air Density – Variation of Atmospheric Pressure

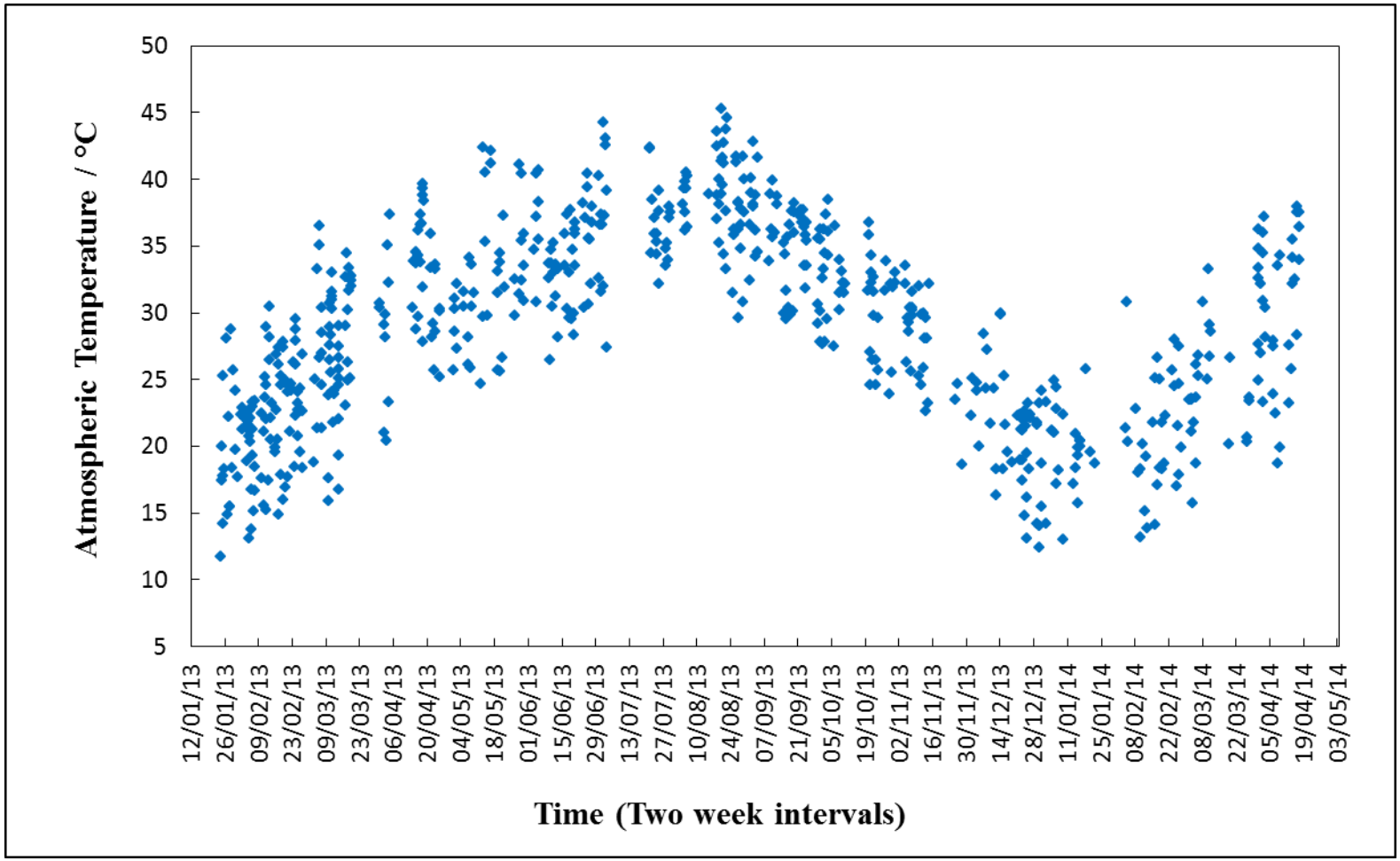


Uncertainty of Force due to air buoyancy, if corrections for pressure, temperature and humidity in the laboratory are not made, is 2.8 x 10^{-6}

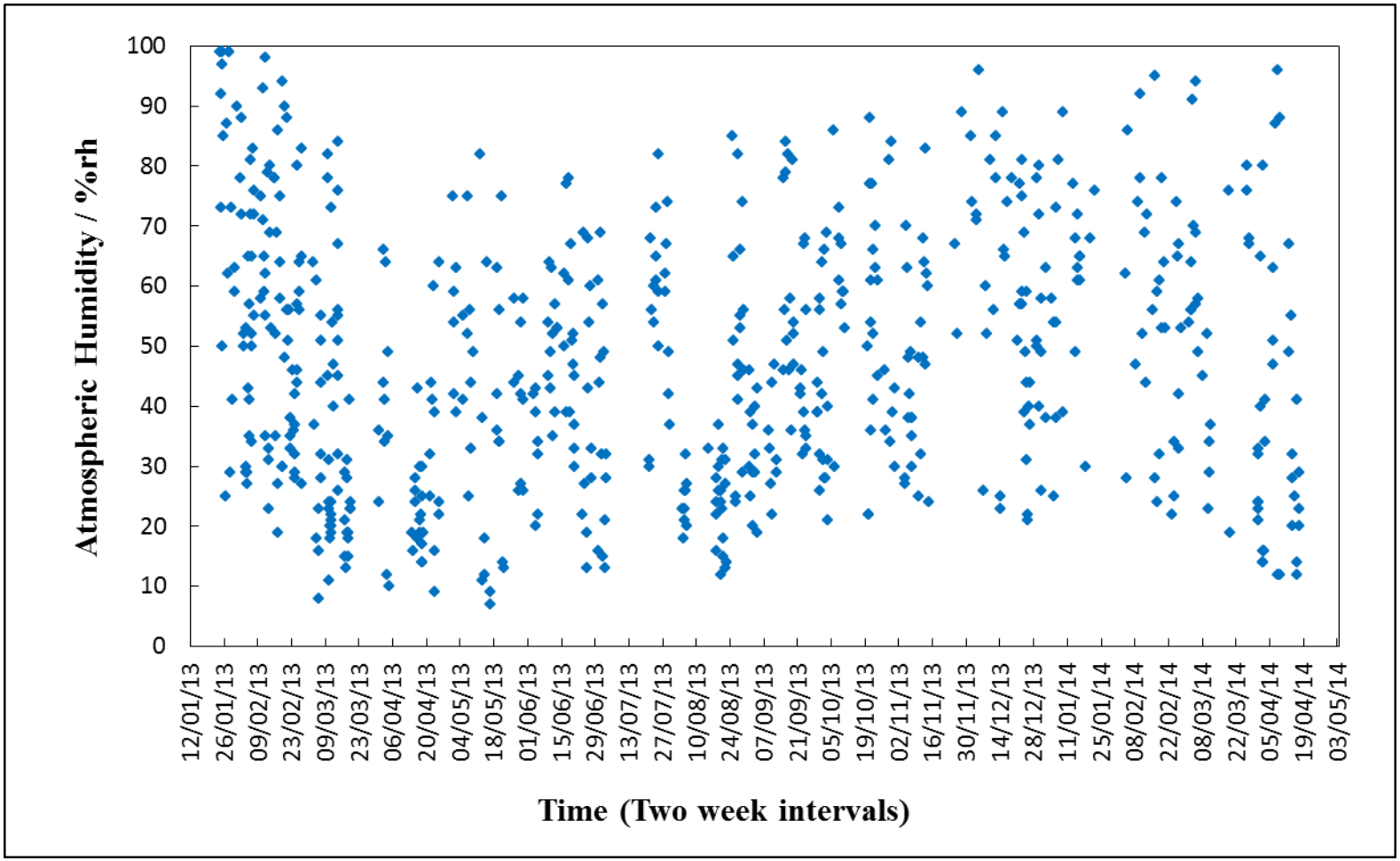
Conclusions

- The measurement of g is not the limiting factor when establishing force, torque and pressure standards using deadweights
- Taking an average value of air density (additional uncertainty of 2.8×10^{-6}) is acceptable for current requirements
- If ever the need arose, corrections for Earth tides could be made to g, and corrections made for changes in air density
- These corrections are needed for the highest level of mass metrology, and the measurement of g at the part in 10^9 level is needed for the redefinition of the kilogram
- For large force and torque machines, the uncertainty will likely be limited by the uncertainty of mass measurement

Variation of Atmospheric Temperature



Variation of Atmospheric Humidity



Thank you