FBGs characterisation under controlled atmospheres

2023 February & March Runs

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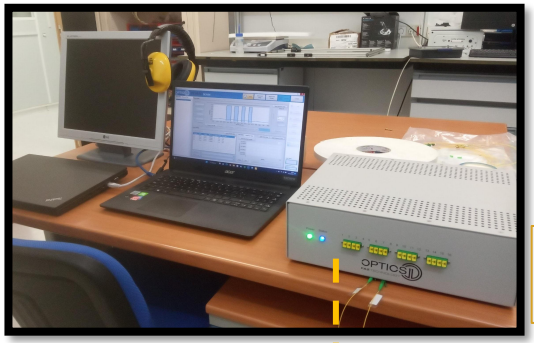
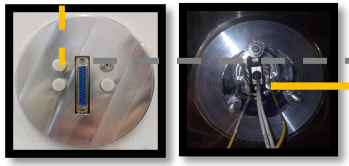
Climatic Chamber

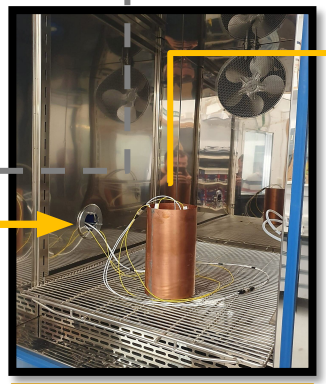


FBG Interrogator

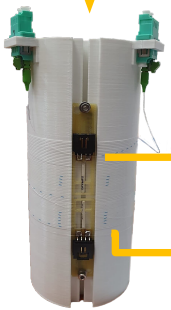
MUX



Pass-through



Climatic Chamber



Cylinder holder

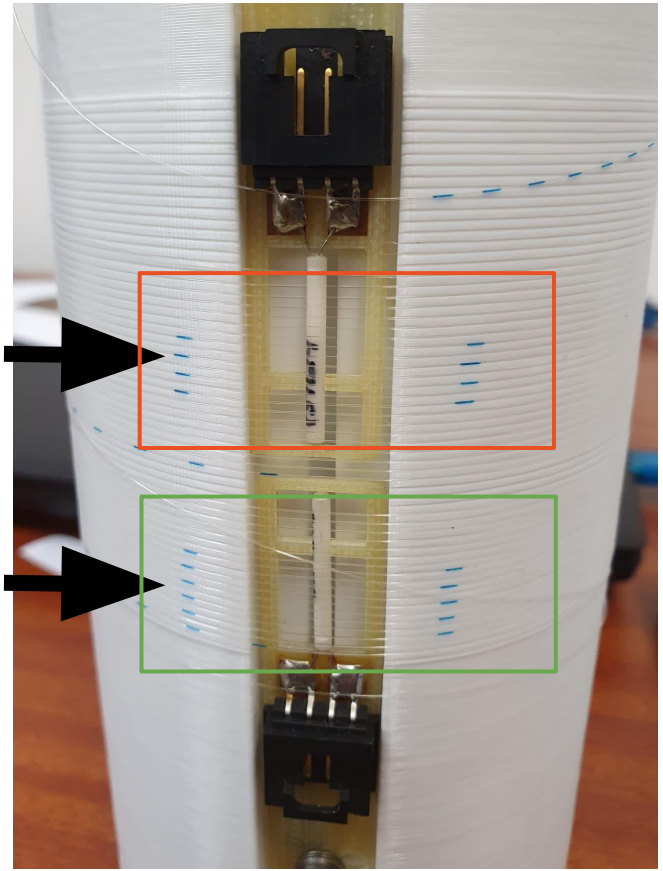
RTD

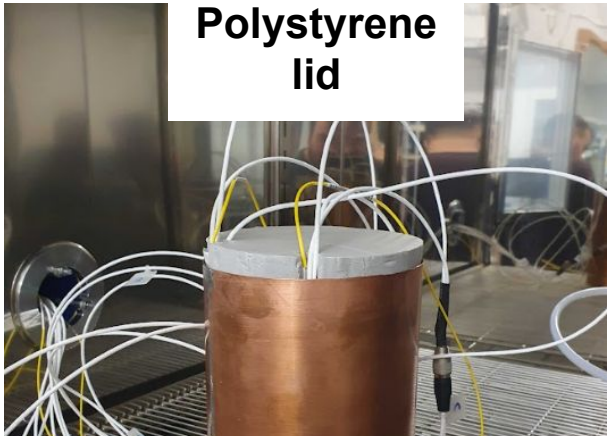
FBGs

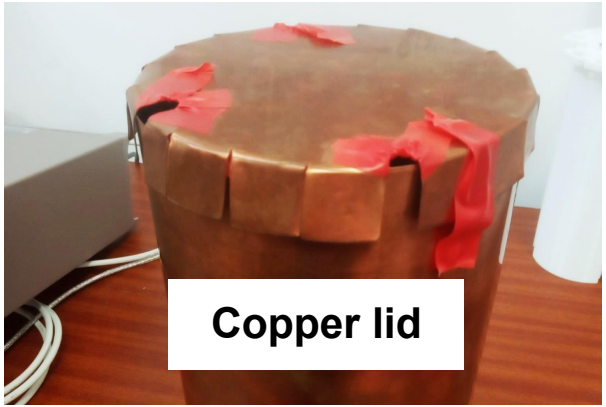
Setup

ORMOCER

ORMOCER-T







Description of the Runs

February Runs: 4+1 temperature runs.

- **Temperature runs**: All runs were different in profile, the two types of fibre coatings were studied in all of them.
- **RTD calibration run**: Run to perform the relative calibration of the RTD sensors used.

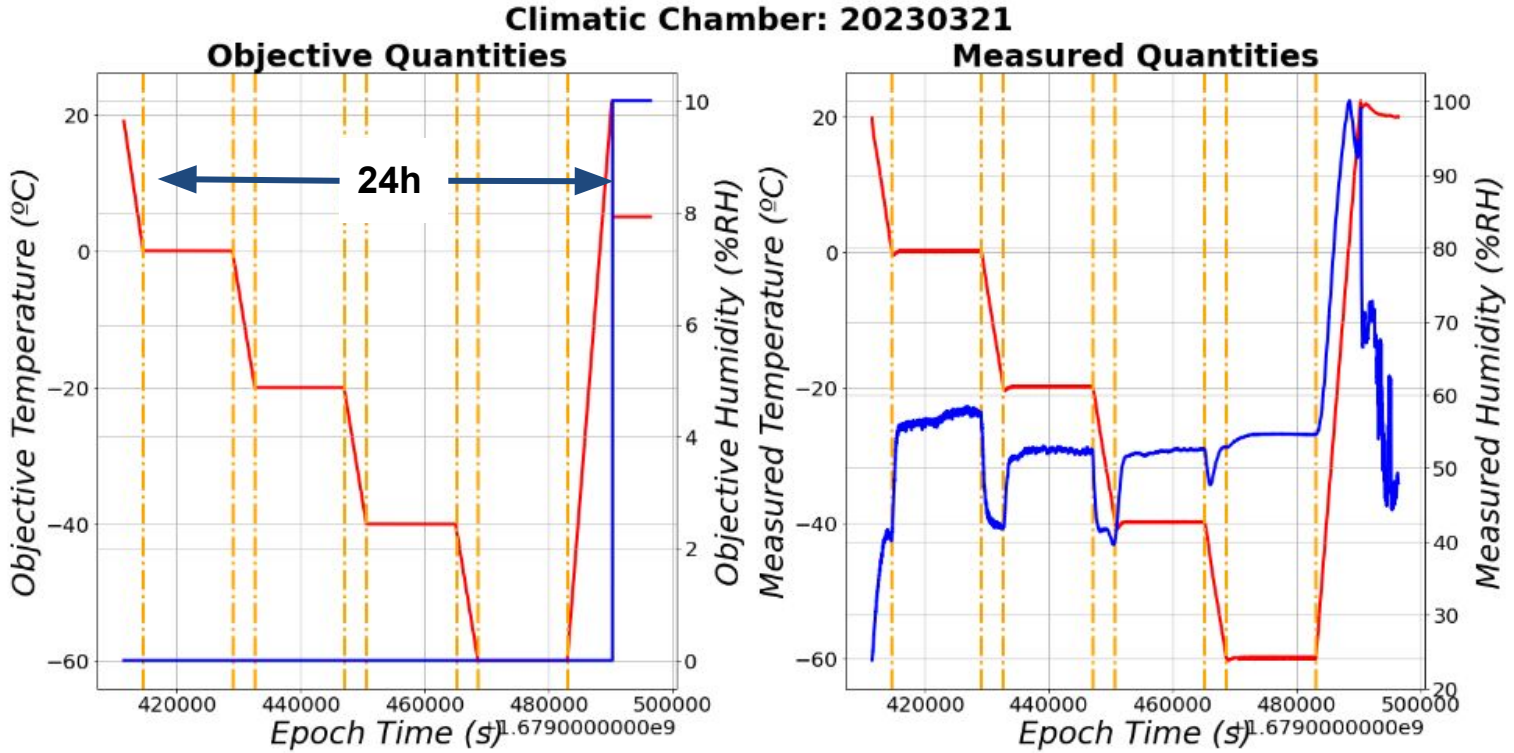
Mainly focused on stability, hysteresis and short-term reproducibility studies.

March Runs: 4 temperature runs & 3 humidity runs.

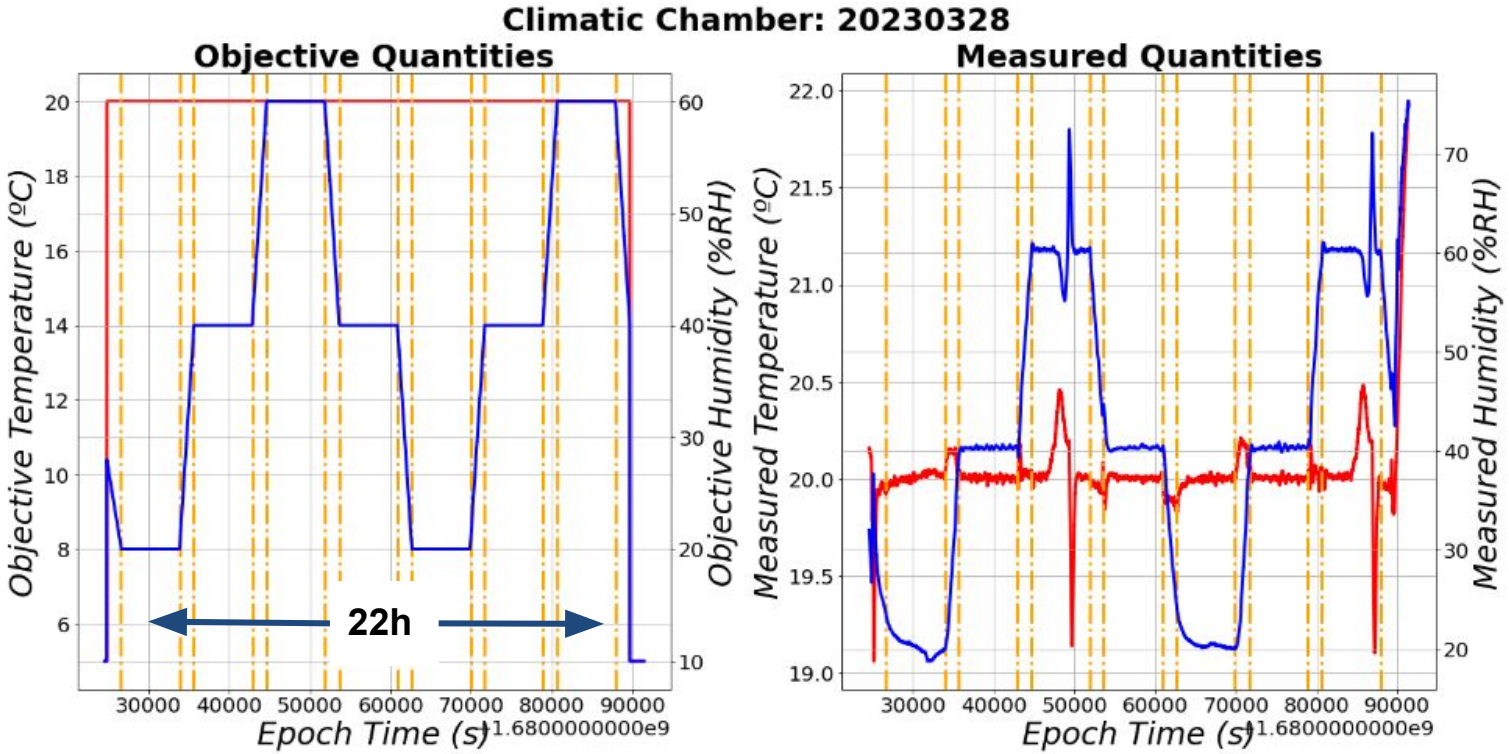
- **Temperature runs**: All runs were identical in temperature profile. 2 of them with just one fibre, and 2 with the two fibres.
- **Humidity runs**: All runs were identical in humidity profiles. 2 runs with just one fibre and 1 with the two fibres.

Mainly focused on long-term reproducibility studies, under temperature and humidity.

Example Temperature Run profile



Example Humidity Run profile



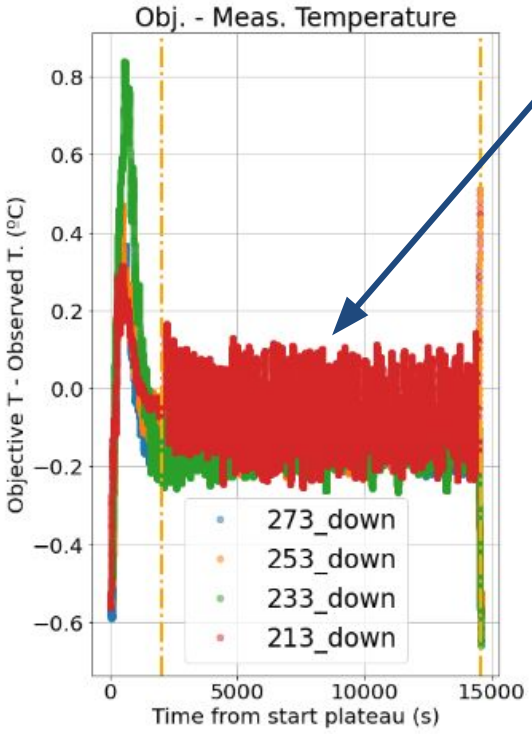
Characterization parameters: definitions

***Accuracy*: Defined as the *MEAN* of the **difference between the objective and the measured** values of a variable at a certain temperature plateau, that is, for example, when measuring the temperature with the climatic chamber the accuracy is the mean of **(Obj. T - Meas. T)**, and for the humidity **(Obj. RH - Meas. RH) .**

***Repeatability*: Defined as the *MEAN* of the *accuracies dispersion (STD)* at certain plateau, over different runs. It is calculated as the *ERROR of the mean accuracy* at certain plateau.

***Stability*: Defined as the *STD* of the variable under study (*temperature, humidity or wavelength*) at a certain temperature plateau.

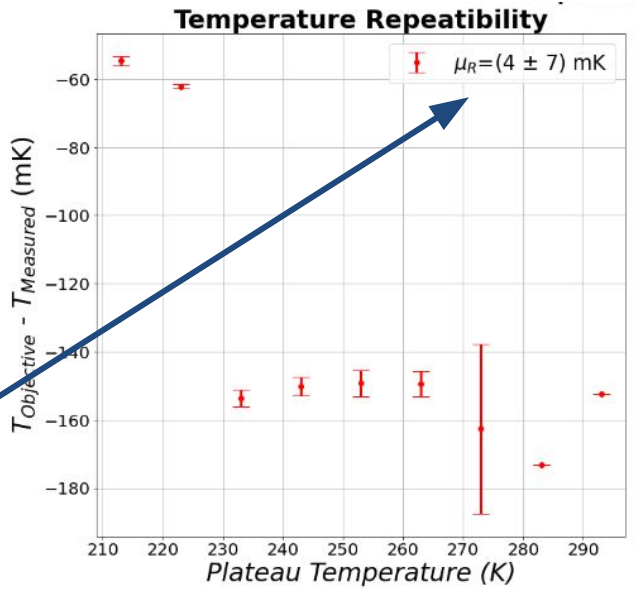
Examples of the accuracy and repeatability plots



Mean value from each of the curves is defined as the ACCURACY of the measurement.

There are N accuracies per temperature plateau, so the mean accuracy is defined as the MEAN of the N accuracies, and the **repeatability** is defined as the STD of the N accuracies.

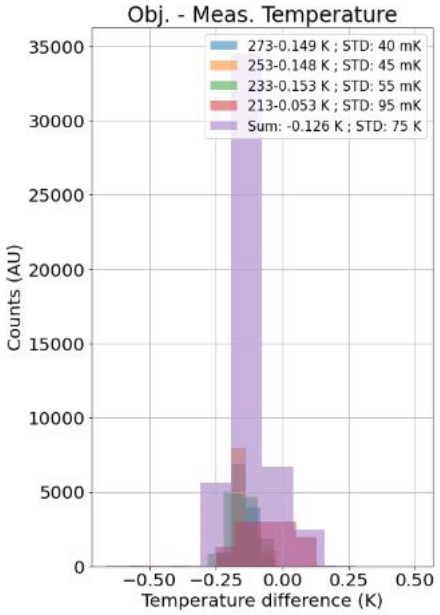
Example of the accuracy from the climatic chamber characterization.

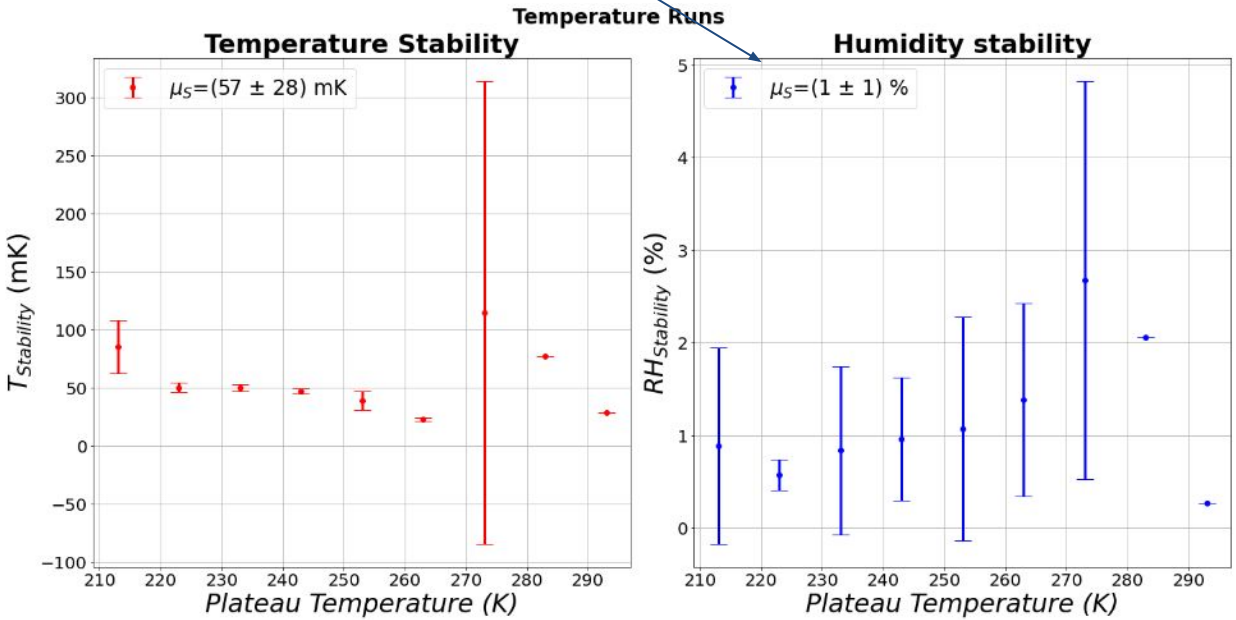


Example of a repeatability plot from the climatic chamber characterization. Repeatability value is the mean of the error bars.

Characterization parameters

Stability: Defined as the STD of the variable under study (temperature, humidity or wavelength) at a certain temperature plateau. **Mean stability** defined as the mean of the stabilities over the different plateaus. Stability value is the mean of the DATA POINTS.





Characterization of the climatic chamber.

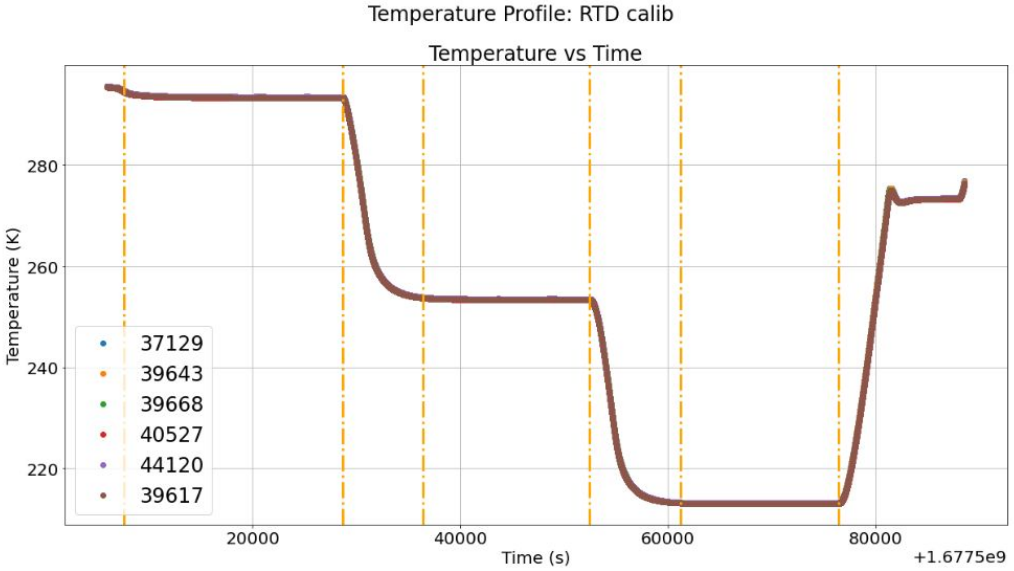
The performance of the climatic chamber under temperature or humidity profiles can be summarized in the following table.

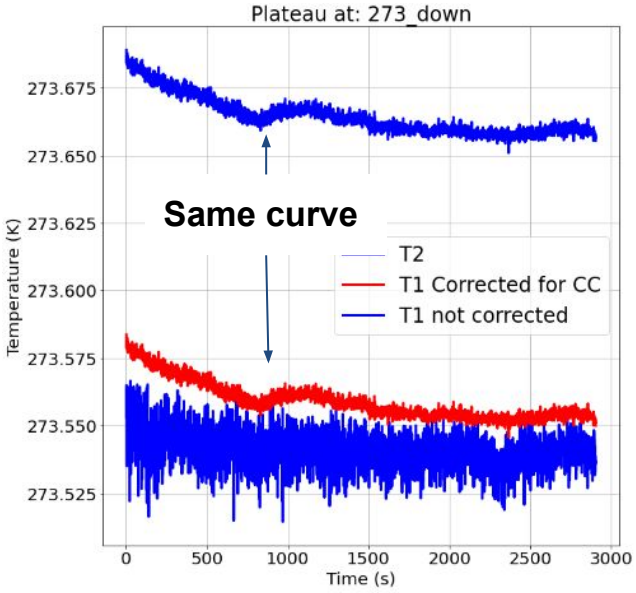
Temperature reproducibility seems to be enough to perform our studies. Humidity repeatability appears to be larger than needed, and represents a significant systematic error.

	Temperature Runs		**Humidity Runs**	
	Temperature	**Humidity**	**Temperature**	**Humidity**
Repeatability	*(4 +- 7) mK*	*(3 +- 2) %*	*(11 +- 11) mK*	*(1 +- 1) %*
Stability	*(57 +- 28) mK*	*(1 +- 1) %*	*(67 +- 63) mK*	*(1 +- 1) %*

Calibration of the RTDs: 20230227

To perform a relative calibration between the RTD sensors used in all climatic chamber runs, we used the same setup used for the RTD calibration for DUNE-HD sensors.

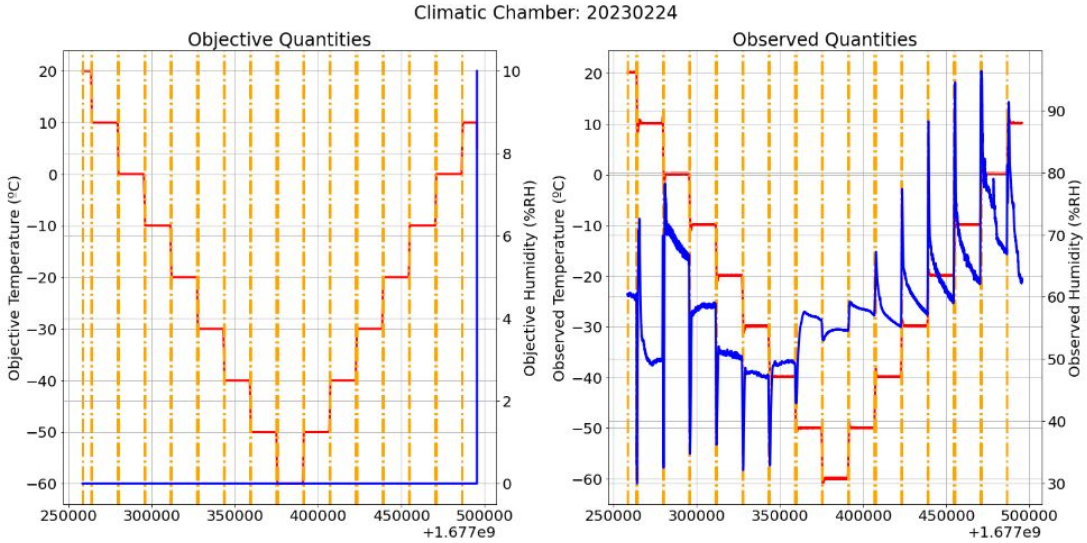




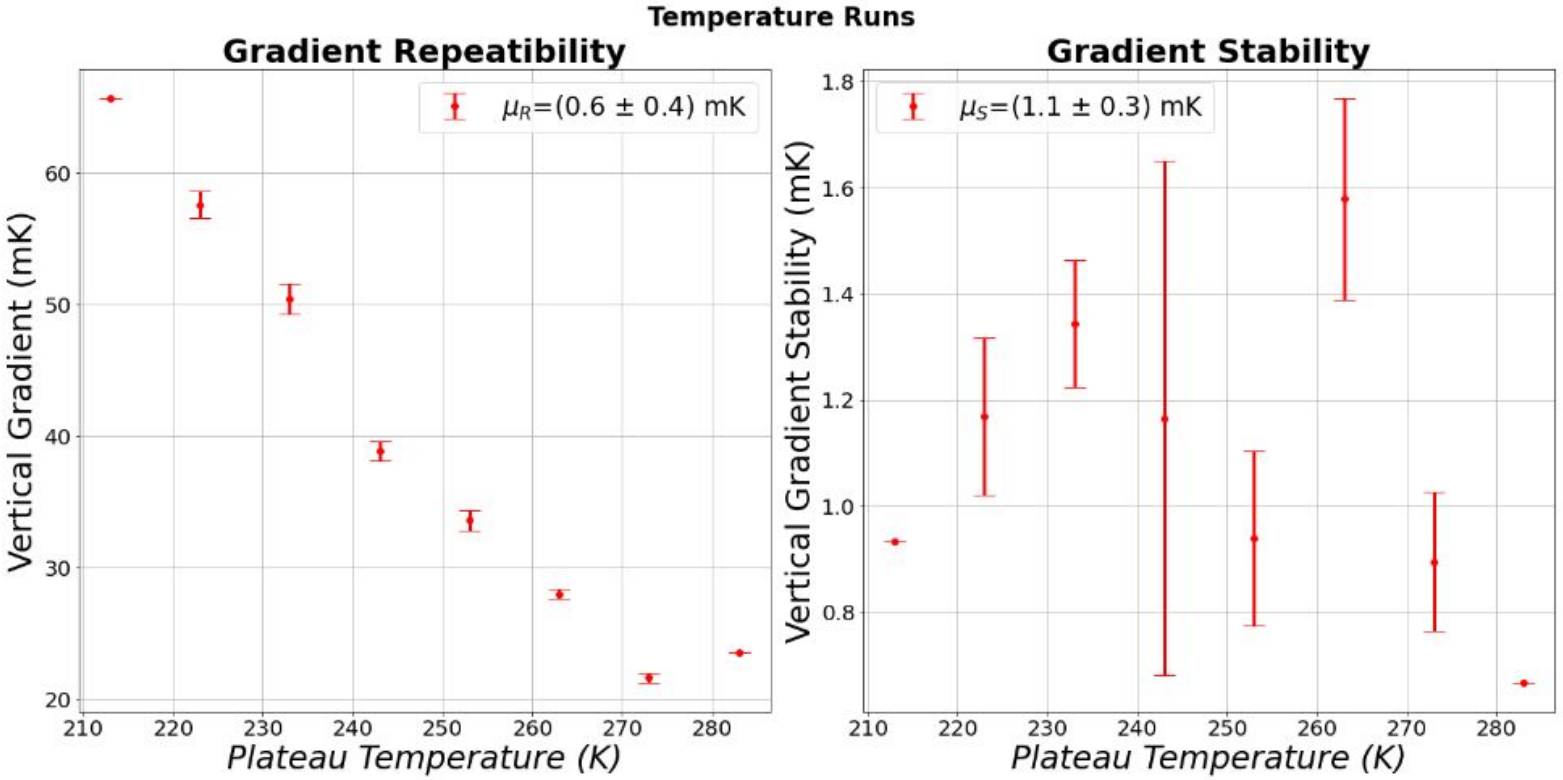
Definition of short- and long-term studies

The repeatability and stability of the setup can be defined in short- or long-term terms.

- **Short-term**: studies performed over a **single run** (20230224) that has a ramp-up & ramp-down. It allows to understand the performance over a consecutive thermal cycle.
- **Long-term**: studies performed over different runs from different days, with different temperature profiles in principle.



Gradient Repeatability of the setup: short-term



Characterization of the RTDs

The performance of the setup under temperature runs can be summarized in the following table.

Repeatability of the temperature gradient indicates **very homogeneous variations of temperature** inside the setup.

	Temperature Runs			
	Long-term		**Short-term**	
	Temperature	**Gradient**	**Temperature**	**Gradient**
Repeatability	*(74 +- 72) mK*	*(8 +- 7) mK*	*(8 +- 8) mK*	*(0.6 +- 0.4) mK*
Stability	*(17 +- 7) mK*	*(3 +- 2) mK*	*(12 +- 4) mK*	*(1.1 +- 0.3) mK*

Characterization of the FBGs: temperature runs

The **same definitions of accuracy, repeatability and stability** apply for the FBG studies.

In this case, the observables are:

- **WL difference**: WL - WL(T=213K)
- **WL offset**: WL_S1 - WL_S2. The measured difference in WL between two sensors at the same instant.

Studies are performed for the two types of coatings, **ORMOCER & ORMOCER-T**, as differences in performance are expected.

Performance of the FBGs: long-term

	Long-term Temperature Runs							
	ORMOCER				ORMOCER-T			
	Wavelength Diff.		Offset		Wavelength Diff.		Offset	
	Repr. (pm)	Stab. (pm)	Repr. (pm)	Stab. (pm)	Repr. (pm)	Stab. (pm)	Repr. (pm)	Stab. (pm)
S1	*11+-9*	*1.9+-1.7*	*X*	*X*	*8+-8*	*1.4+-2*	*X*	*X*
S2	*16+-15*	*1.7+-1.3*	*7+-8*	*0.3+-0.4*	*6+-7*	*1.3+-1.5*	*8+-7*	*0.3+-0.4*
S3	*15+-15*	*1.7+-1.2*	*11+-9*	*0.3+-0.6*	*9+-10*	*1.4+-1.9*	*12+-11*	*0.2+-0.2*
S4	*13+-13*	*1.7+-1.1*	*10+-9*	*0.3+-0.6*	*8+-8*	*1.1+-1.1*	*13+-12*	*0.5+-0.9*

Performance of the FBGs: short-term

	Short-term Temperature Runs							
	ORMOCER				ORMOCER-T			
	Wavelength Diff.		Offset		Wavelength Diff.		Offset	
	Repr. (pm)	Stab. (pm)	Repr. (pm)	Stab. (pm)	Repr. (pm)	Stab. (pm)	Repr. (pm)	Stab. (pm)
S1	*11+-9*	*1.8+-1.7*	*X*	*X*	*4+-4*	*1.2+-2*	*X*	*X*
S2	*17+-17*	*1.7+-1.3*	*6+-9*	*0.3+-0.4*	*4+-3*	*1.1+-1.6*	*3+-7*	*0.3+-0.4*
S3	*14+-14*	*1.7+-1.1*	*4+-8*	*0.4+-0.6*	*5+-5*	*1.3+-1.9*	*5+-10*	*0.2+-0.2*
S4	*14+-14*	*1.6+-1.1*	*4+-9*	*0.3+-0.6*	*6+-7*	*1.0+-1.1*	*6+-11*	*0.5+-0.9*

Significant improvement

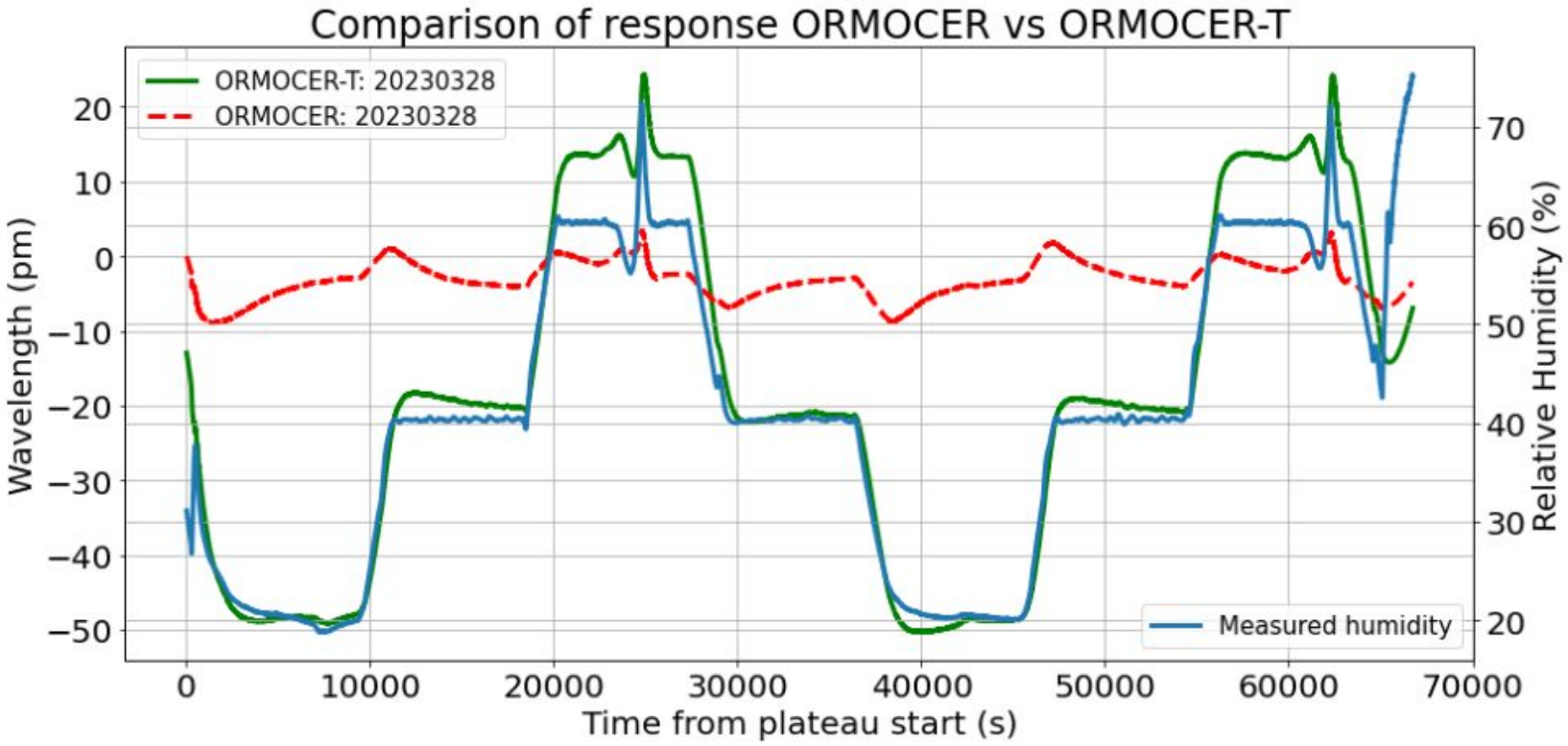
Wavelength repeatability of the FBGs: humidity

For these studies, the situation is a little bit peculiar. It turns out to be that **for the ORMOCER coating we have 3 consecutive runs**, while for the **ORMOCER-T we just have 1 run** (20230328). So,

- For **ORMOCER** coating, studies can be understood as **LONG-term** studies;
- For **ORMOCER-T** coating, studies MUST be understood as **SHORT-term** studies (as there is only one single run).

They SHOULD NOT in principle be comparable at first sight. Although, ORMOCER-T is much more sensitive to humidity by construction.

Comparison of coatings under humidity



Performance of the FBGs: humidity

	Humidity Runs							
	ORMOCER				ORMOCER-T			
	Wavelength Diff.		Offset		Wavelength Diff.		Offset	
	Repr. (pm)	Stab. (pm)	Repr. (pm)	Stab. (pm)	Repr. (pm)	Stab. (pm)	Repr. (pm)	Stab. (pm)
S1	*34+-13*	*6.5+-1.8*	*X*	*X*	*1.1+-0.7*	*1.2+-1.2*	*X*	*X*
S2	*27+-11*	*5.3+-1.5*	*116+-3*	*1.3+-0.3*	*0.3+-0.2*	*1.2+-1.2*	*1+-1*	*0.2+-0.1*
S3	*30+-11*	*5.6+-1.6*	*116+-2*	*1.0+-0.3*	*0.2+-0.1*	*1.1+-1.2*	*1+-1*	*0.3+-0.1*
S4	*33+-15*	*6.3+-1.7*	*7+-3*	*0.6+-0.2*	*0.1+-1*	*1.1+-1.2*	*1+-1*	*0.3+-0.1*

Huge difference in performance between coatings under humidity profiles

Wavelength sensitivity of the FBGs: temperature

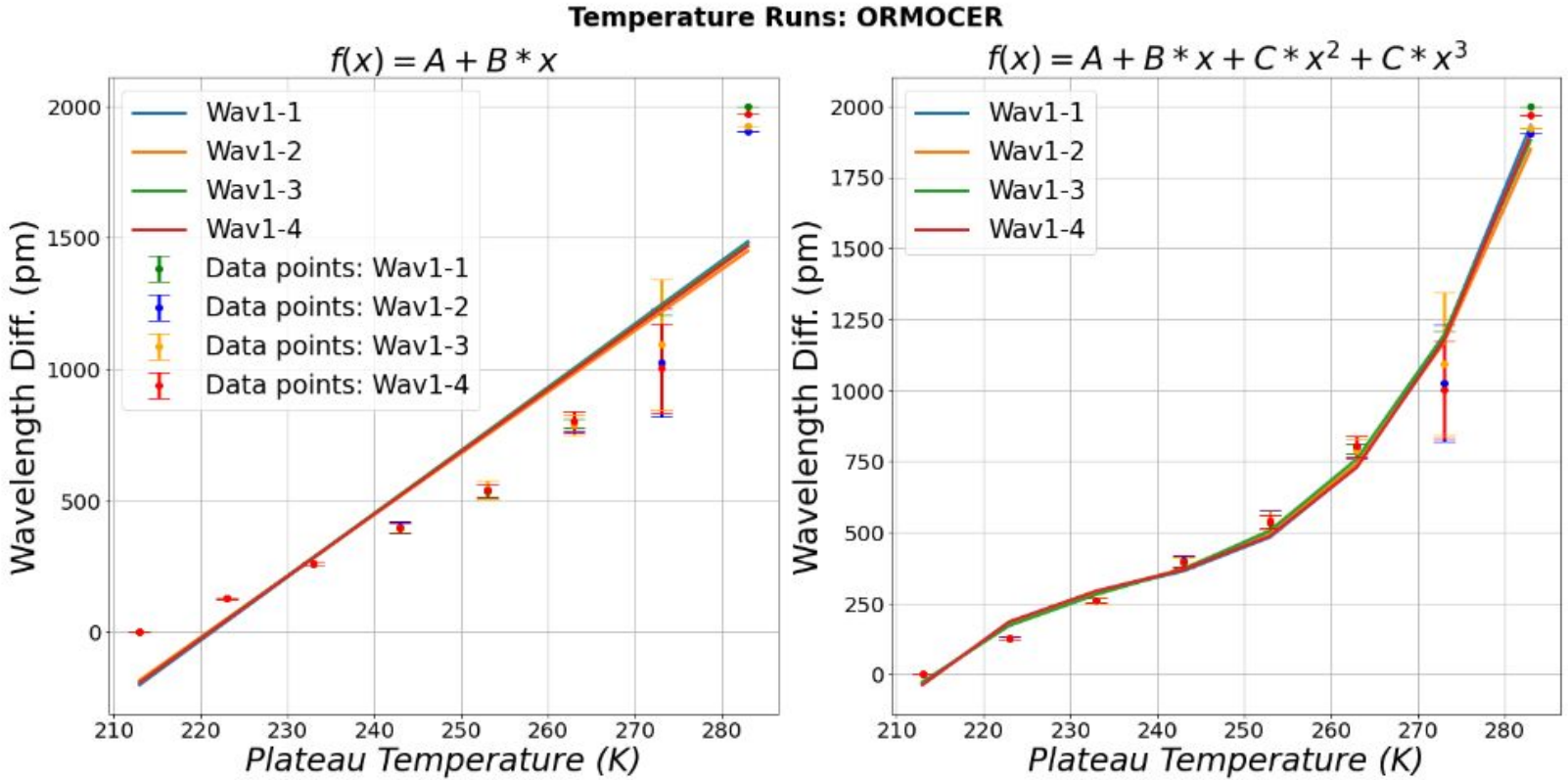
Sensitivity curves are calculated from the quantity defined as Wavelength difference. It is: WL_diff = WL - WL(T=213K).

WL differences are calculated at each plateau as the mean of the WL diff. Values at certain plateau for all runs, and the error bars are the repeatability at that temperature/humidity.

Two polynomial functions are adjusted: linear fit & 3rd degree polynomial fit.

Linear fit represents the mean sensitivity over the whole temperature range.

Temperature sensitivity: ORMOCER



Wavelength sensitivity of the FBGs: humidity

It is important to notice the size of the error bars for the ORMOCER coating. It has 2 main explanations:

- **ORMOCER coating studies are LONG-term studies**;
- **ORMOCER coating shows a relaxation phenomena** that changes the response of the measurement over consecutive humidity cycles. This phenomena will be studied in more detail in further analysis (see next slides).

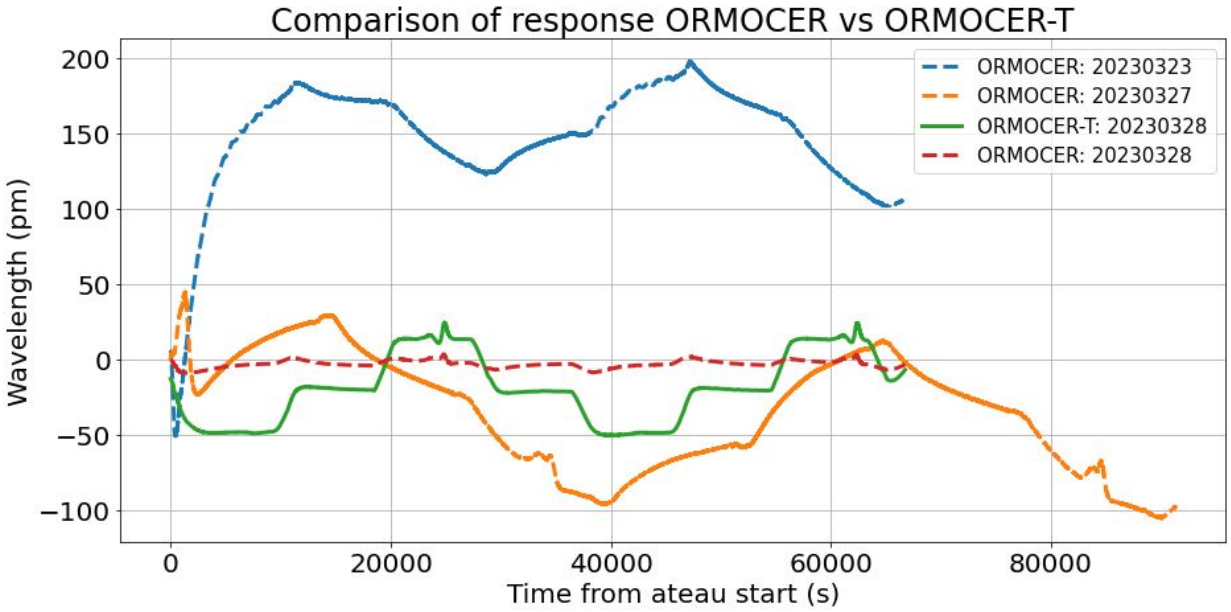
For the ORMOCER-T coating, the sensitivity MUST be understood as a short-term sensitivity, although it seems that ORMOCER-T coating is much more sensitive than ORMOCER under humidity cycles.

Humidity sensitivity: relaxation

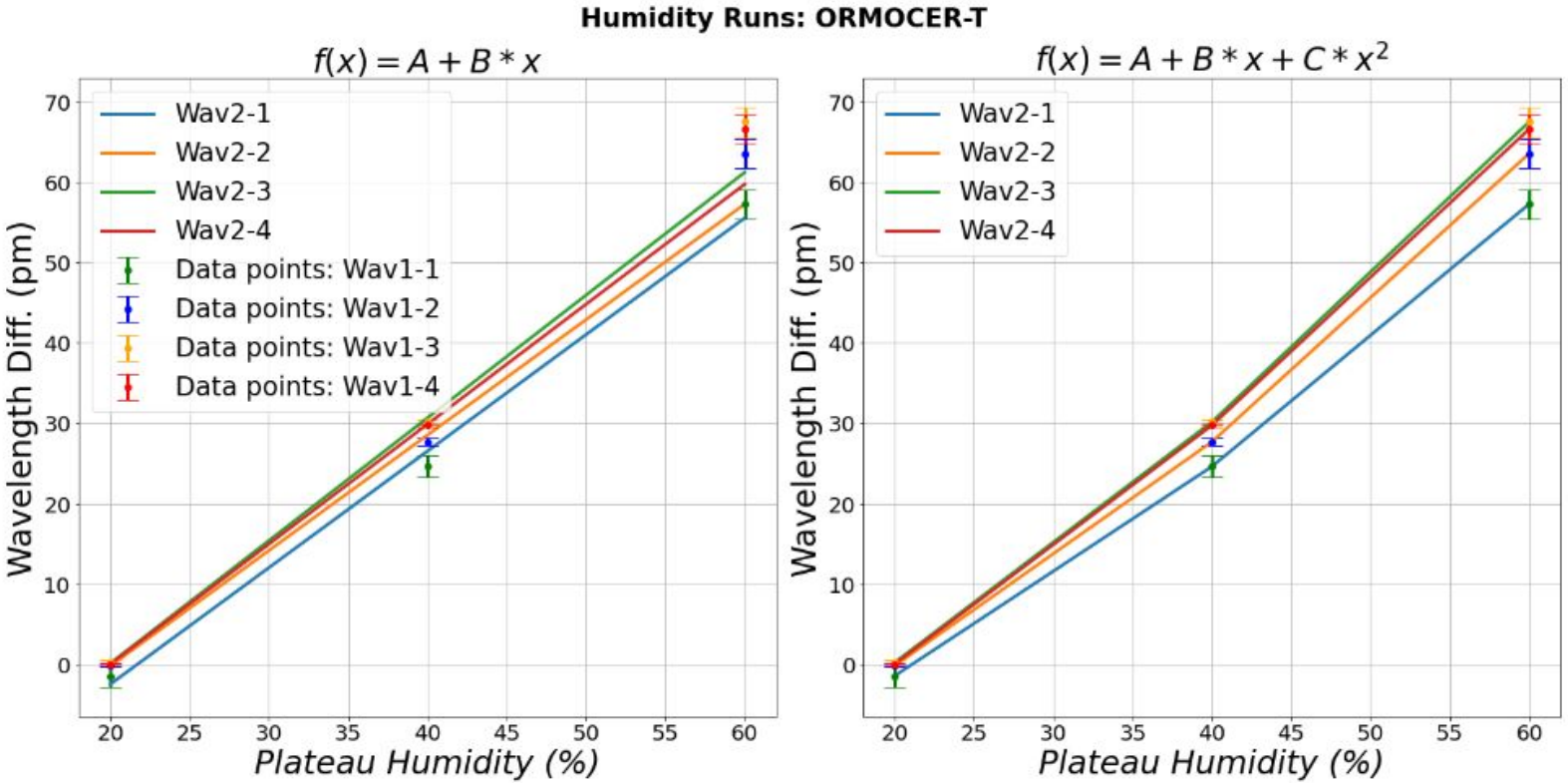
The blue and orange curves were taken without unrolling the fibres, after unrolling and roll back again with the two fibres on 20230328, it turns out that the response changed dramatically for the ORMOCER fibre.

Blue, orange and red lines are from the same sensor of the ORMOCER fibre, under exact same humidity profiles.

Green curve was taken at the same time as the red, but the fibre is ORMOCER-T.



Humidity sensitivity: ORMOCER-T



Sensitivity studies: Temperature & Humidity

Sensitivity values			
ORMOCER		**ORMOCER-T**	
Temperature (pm/K)	**Humidity (pm/%)**	**Temperature (pm/K)**	**Humidity (pm/%)**
23.6 +- 0.2	*-1.2 +- 1.2*	*24.5 +- 0.5*	*1.47 +- 0.03*

Conclusions: current temperature resolutions

To estimate the current resolutions in temperature and in temperature offset provided by FBGs, we take the obtained repeatabilities in wavelength diff. and in wavelength offset and use the sensitivity to estimate these values.

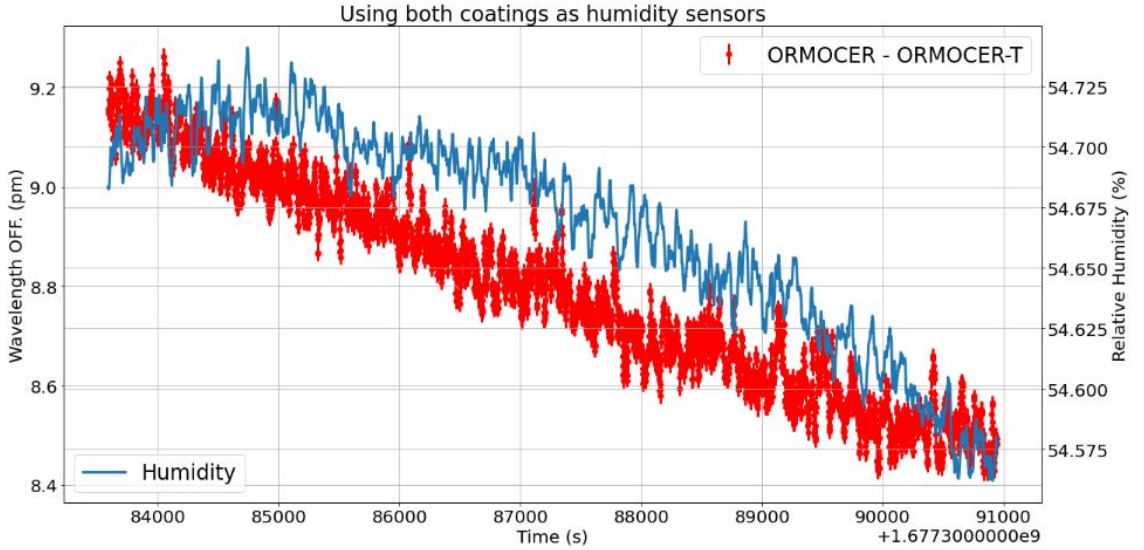
	Temperature Resolution			
	ORMOCER		ORMOCER-T	
	Temperature (mK)	Gradient (mK)	Temperature (mK)	Gradient (mK)
Estimation (mK)	*~580*	*~200*	*~300*	*~180*
Temperature Induced (mK)	*~100*	*~20*	*~100*	*~20*
Humidity Induced (mK)	*~180*	*~150*	*~180*	*~150*

Next steps: continue the analysis.

A more detailed analysis is currently ongoing, with several lines still opened.

An example: create a humidity profile INSIDE of the setup taking advantage of the non-humidity sensitivity of the ORMOCER coating.

The offset between ORMOCER and ORMOCER-T is correlated with humidity.



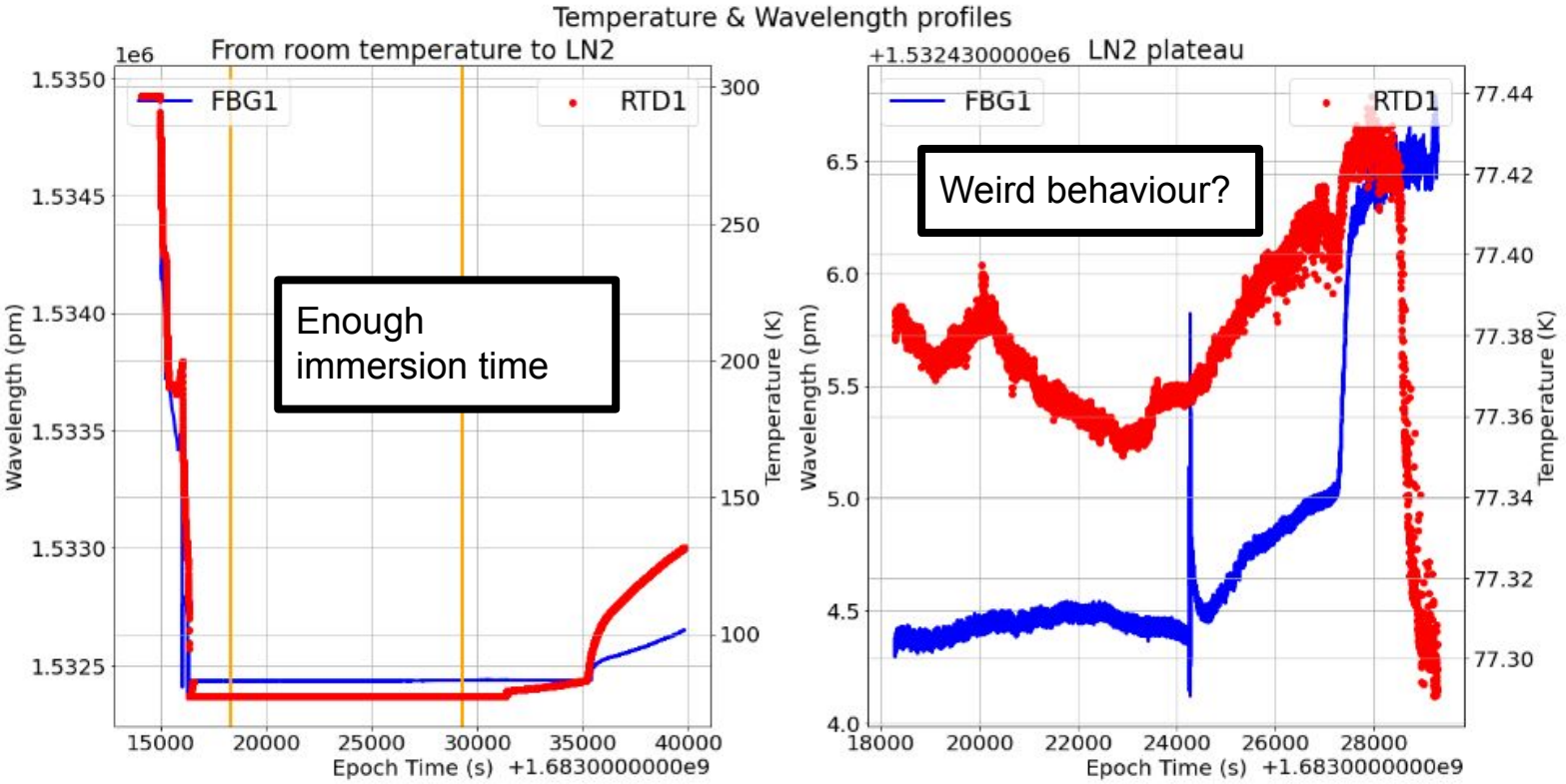
Next Steps: towards cryogenic temperature.

The next step is to start performing **cryogenic tests in LN2**, for that, a measurement plan has been arranged:

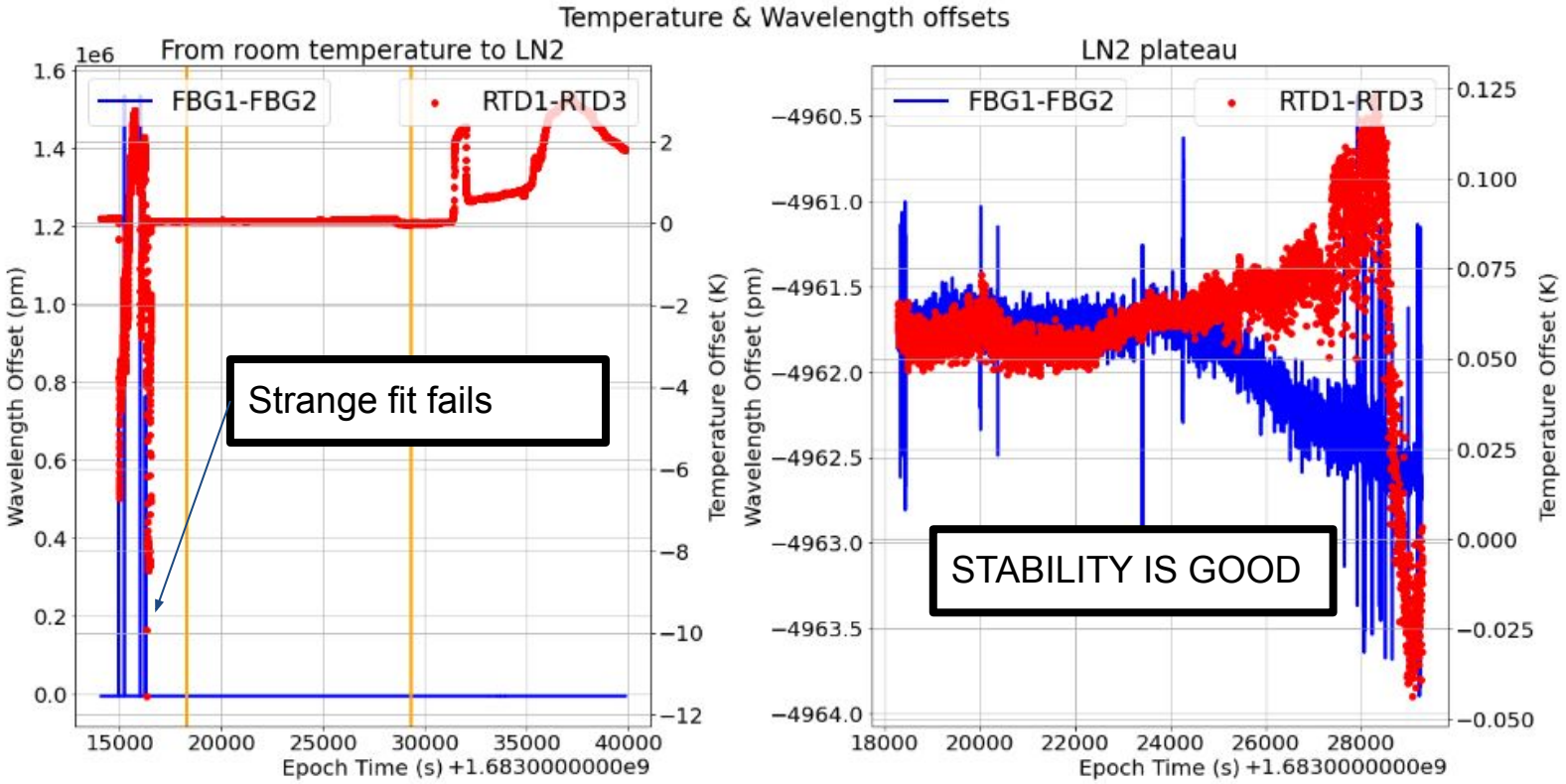
- The setup to slowly cool-down and heat-up the FBG sensors has been designed and first tests are being carried out;
- Both repeatability and stability tests are being be performed;
- Will take advantage of the small temperature variations in LN2 temperature to estimate the sensitivity at that temperature;
- **FBG sensors will be again characterized** after the first LN2 tests **in the climatic chamber** to check for possible alterations in their response;
- After these firsts tests, further techniques in order to increase sensitivity (and therefore resolution) of the FBG sensors will be applied.

A very similar version of this presentation will be presented in the next CALCI meeting (May 4th) and hopefully in the coming May Collaboration Meeting.

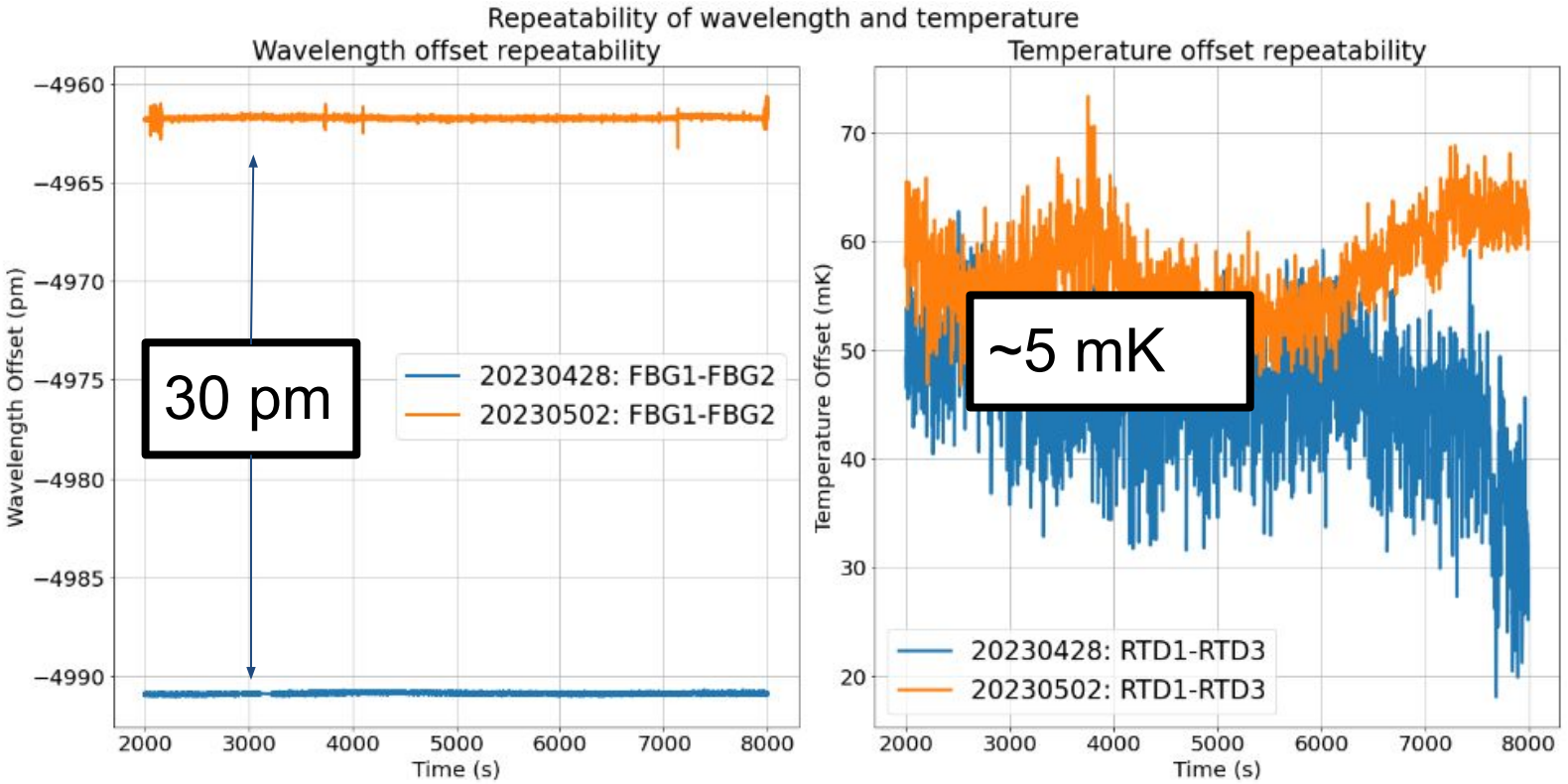
LN2 tests: cool-down process.



LN2 tests: stability of offsets.



LN2 tests: repeatability studies.



First LN2 tests: a lot to understand.

There are several critical points to address before continuing with the LN2 studies:

1. **Improve the isolation of the setup**: PTFE containers yesterday suddenly broke and we need to replace them as soon as possible.
2. **Replicate a similar setup as that used for the RTD calibration**. It is key to create several **concentric LN2 volumes** to keep temperature stable.
3. **Understand the behaviour of the fit** at these temperatures: amplitudes of signals decrease as temperature diminished and therefore the fit becomes less and less accurate.
4. Understand the **physics that governs the reflection at those temperatures**, explore the behaviour of the light polarisations, ensure external conditions are repeatable (strain, stress, positioning, routing…) -> **Literature is key**.
5. Perform more **climatic chamber tests** in order to understand what has changed with respect to the situation before the first immersion.
6. It is **VERY important to measure before and after immersions**: for that we need a setup where we can keep temperature stable enough at room temperature.

A lot more will appear… Thank you!