Temperature Sensitivity of HySpex VNIR-3000N's and HySpex SWIR-384's Spectral Responses

Gabriel Scheib[1*], Andreas Baumgartner[1], Claas Köhler[1]

[1]German Aerospace Center (DLR), Remote Sensing Technology Institute
*gabriel.scheib@dlr.de

Challenge

- DLR's user service Optical Airborne Remote Sensing (OpAiRS) operates two hyperspectral cameras of Norsk Elektro Optikk (NEO): HySpex VNIR-3000N, HySpex SWIR-384
- Both pushbroom cameras have optical benches that are neither vacuumized nor temperature stabilized
- Only SWIR-384's detector is temperature stabilized (150 K)
- Both are calibrated in DLR's Calibration Home Base for Imaging Spectrometers (CHB) under laboratory conditions[1,2]
- In-flight conditions may differ significantly as cameras are exposed to the environment outside the aircraft
- Cameras are designed to perform in this environment, yet, it is critical to quantify in-flight instrument stability
- Typical in-flight conditions:
  Ambient temperature: 10–25 °C (outliers down to 2 °C)
  Data acquisition times: 30–120 minutes
  Pressure: ~690–780 hPa (outliers <690 hPa)

HySpex Camera	Spectral Range [nm]	Spectr. FWHM [nm]	Spectr. Chan-nels	Spatial Pixels	Field of View
VNIR-3000N	400–994	2.5–7.5	700	3408	16.8°
SWIR-384	952–2516	5.5–8.3	288	384	15.9°

Objective of this work

- The objective is to study the temperature sensitivity of the cameras' spectral responses, namely spectral shift, for typical in-flight ambient temperatures
- We report on spectral shift results obtained with a spectral line lamp during OpAiRS flight campaigns with ambient temperatures of 2.5–18.0 °C at 660–750 hPa
- We compare the in-flight measurements to laboratory measurements of spectral line lamps with a temperature-controlled compartment setup

Methodology

Temperature-controlled compartment setup

- Insulated box with temperature control unit
- Camera looks through lens at light field of integrating sphere illuminated by spectral line lamps
- Spectral lines[3] of Mercury (Hg), Krypton (Kr) and Xenon (Xe) lamps are used to cover most of cameras' wavelength ranges
- Set temperatures (±0.3 °C) chosen to cover typical in-flight temperature
- Lamp lines measurement >50 minutes after set temperature is reached (cool down/ heat up time ~30 minutes)

HySpex Camera	Temperatures [°C]	Spectral lines [nm] at 22°C, 950 hPa, 45% rel. hum.
VNIR-3000N	7.1, 12.0, 17.0, 21.9, 27.0	Hg: 435.84, 546.09 Xe: 881.96, 979.99
SWIR-384	7.2, 12.1, 17.1, 21.9, 27.1	Hg: 1014.00, 1529.62 Kr: 2190.31* *Extrapolated refractive index of air[4] value used

In-flight measurements

- Hg lamp lines measurement with Spectralon beneath camera shortly after aircraft ground roller door is closed after measurement flight lines
- Ambient temperature uncertainty estimation of ±3 °C due to temperature gradient between hatch and aircraft cabin

HySpex Camera	Temperatures [°C]	Spectral lines [nm] at 22°C, 950 hPa, 45% rel. hum.
VNIR-3000N	2.5, 10.0, 11.5, 18.0	Hg: 435.84, 546.09
SWIR-384	2.5, 10.0, 11.5, 18.0	Hg: 1014.00, 1529.62

Evaluation

- Calculation of effective spectral line wavelengths[4] from present environmental parameters temperature, pressure, rel. humidity, CO2 (450 ppm assumed)
- Fit of line signals by sampling line wavelengths with cameras' spectral response functions determined during laboratory calibration with spectral shift as fit parameter
- Subtraction of recent spectral shift results at 20–22 °C from fitted shifts to account for instrument variation over time

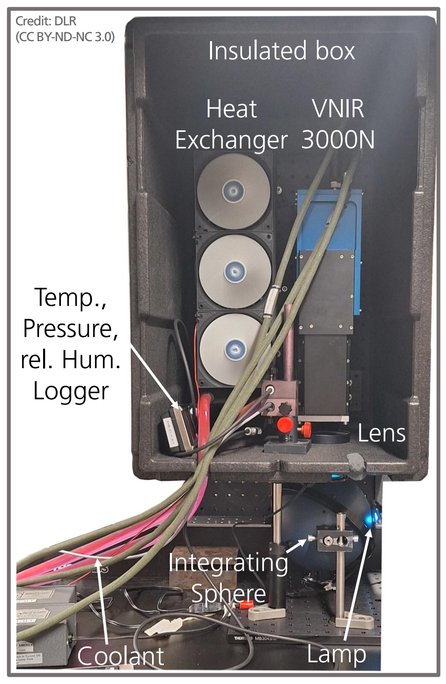
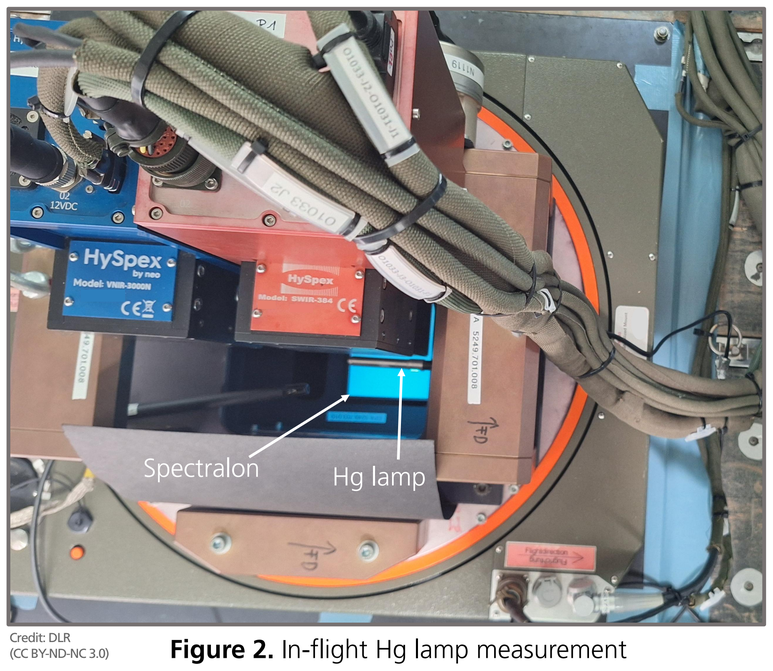


Figure 1. Temperature-controlled compartment setup



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Figure 2. In-flight Hg lamp measurement

VNIR-3000N results

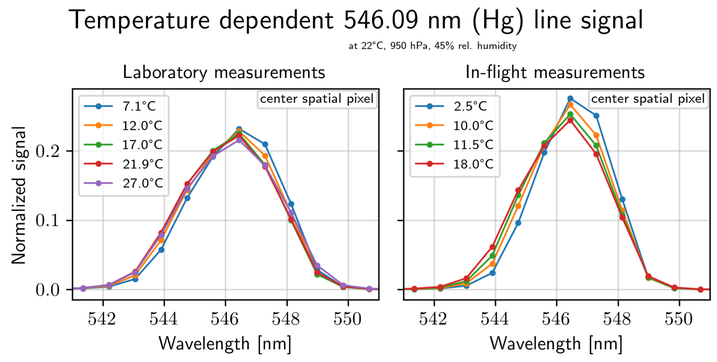


Figure 3. Temperature dependent 546.09 nm (Hg) line signal for center spatial pixel. Spectral shift due to refractive index change of air negligible in each subfigure (<0.01 nm).

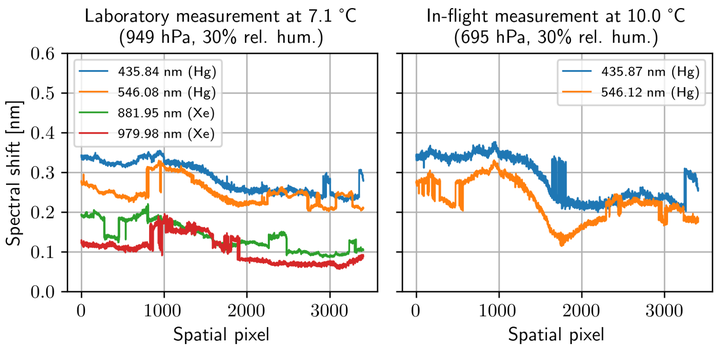


Figure 4. Wavelength dependent spectral shifts for exemplary laboratory measurement at 7.1 °C and in-flight measurement at 10.0 °C. Uncertainty estimated to ±0.15 nm mainly due to reference measurements and spectral response functions uncertainty.

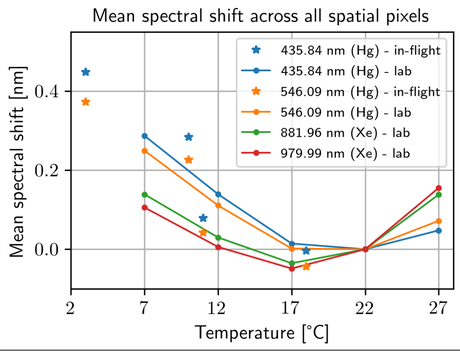


Figure 5. Temperature dependent mean spectral shift across all spatial pixels. Spatially dependent values may spread up to ±0.15 nm around the mean, see e.g. Figure 4.

SWIR-384 results

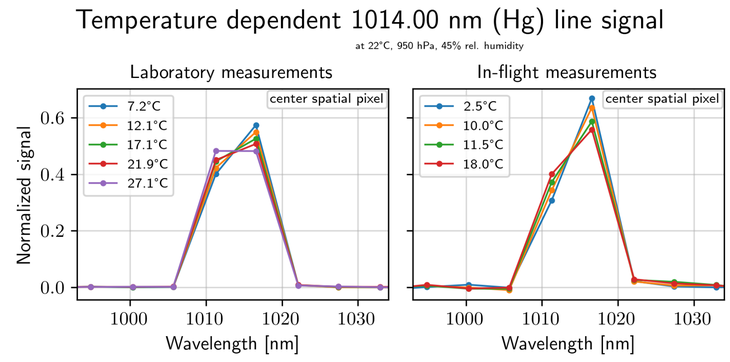


Figure 6. Temperature dependent 1014.00 nm (Hg) line signal for center spatial pixel. Spectral shift due to refractive index change of air negligible in each subfigure (<0.025 nm).

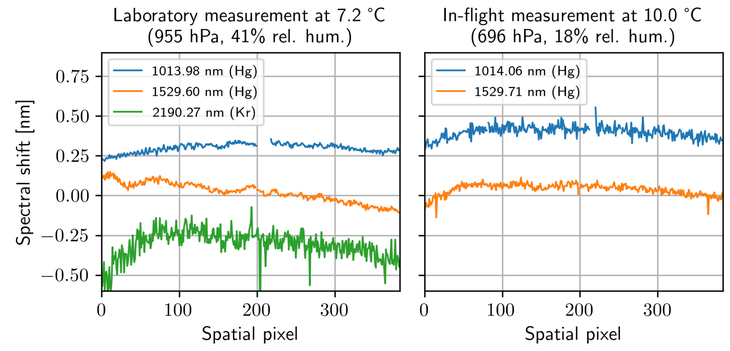


Figure 7. Wavelength dependent spectral shifts for exemplary laboratory measurement at 7.2 °C and in-flight measurement at 10.0 °C. Uncertainty estimated to ±0.2 nm mainly due to reference measurements and spectral response functions uncertainty.

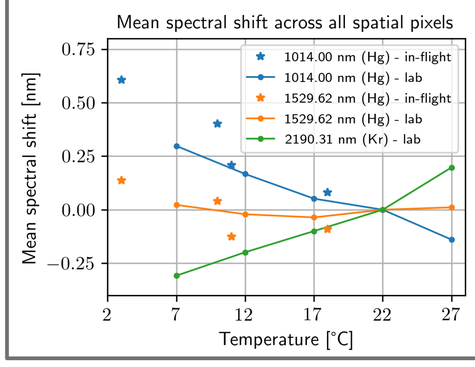


Figure 8. Temperature dependent mean spectral shift across all spatial pixels. Spatially dependent values may spread up to ±0.2 nm around the mean, see e.g. Figure 7.

Discussion

- Laboratory study shows temperature dependent spectral line shifts for all spatial pixels
- Spectral shifts are wavelength dependent for each camera
- In-flight measurements show similar spectral shift trends and similar shift ranges for decreasing ambient temperature
- Estimated VNIR-3000N spectral shift window:
  -0.1 to 0.4 nm for 10–25 °C (<20% of spectral FWHM)
- Estimated SWIR-384 spectral shift window:
  -0.4 to 0.5 nm for 10–25 °C (<10% of spectral FWHM)
- In-flight measurements show a narrowing of the spectral responses for VNIR-3000N (see Figure 3), which is not fully explained by ambient temperature change
- Further investigation of pressure change impact on shape of spectral response functions needed

Conclusion

- Expected spectral shifts for in-flight temperatures 10–25 °C small compared to spectral resolution
- Spectral shifts due to, e.g., colder in-flight temperatures may add to spectral shifts due to instrument variation over time
- Possible implementation of temperature dependent spectral shift correction if high spectral accuracy required
- Effect of pressure on shape of spectral response functions should be investigated

References

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[2] Baumgartner, A. (2022). "Traceable Imaging Spectrometer Calibration and Transformation of Geometric and Spectral Pixel Properties." (Dissertation, University of Osnabrück, Germany).
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[4] P. E. Ciddor, "Refractive index of air: New equations for the visible and near infrared," *Appl. Opt. 35, 1566 (1996)*