

Measurement Standards for Upper Atmospheric Temperature, Humidity, and Environmental Gases

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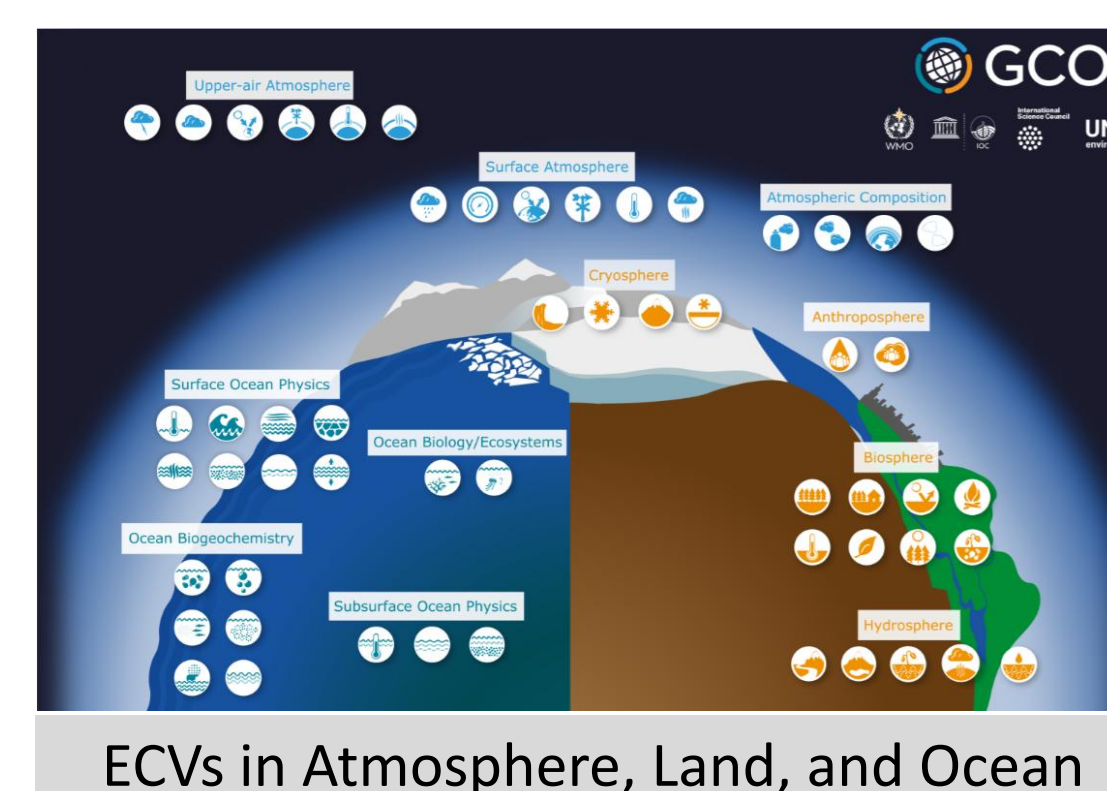
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Abstract

- Atmospheric conditions such as temperature, humidity, and environmental gases are vital for weather and climate models but face measurement challenges in the upper atmosphere.
- KRISS has developed the Upper Air Simulator (UAS) to improve SI-traceability and accuracy of upper-atmosphere measurements through consistent and reliable evaluation of radiosondes.
- KRISS is developing lightweight, modular radiosonde sensors for precise temperature and humidity measurements, along with systems to monitor environmental gases, improving efficiency and scalability in atmospheric observations.

Introduction

- Essential Climate Variables (ECVs)**
 - ECV is a physical, chemical or biological variable or a group of linked variables that critically contributes to the characterization of Earth's climate.
 - World Meteorological Organization (WMO) Global Climate Observing System (GCOS) specifies 55 ECVs in Atmosphere, Land, and Ocean.
- ECVs in Upper Atmosphere**
 - Temperature, Water Vapour, Earth Radiation Budget, Wind Speed & Direction, and Lightning
- Radiosondes**
 - Radiosonde is a telemetry device with temperature, humidity sensors, and etc.
 - Flown by a balloon to measure meteorological parameters up to 35 km
 - 1,000,000 devices/yr are used worldwide.



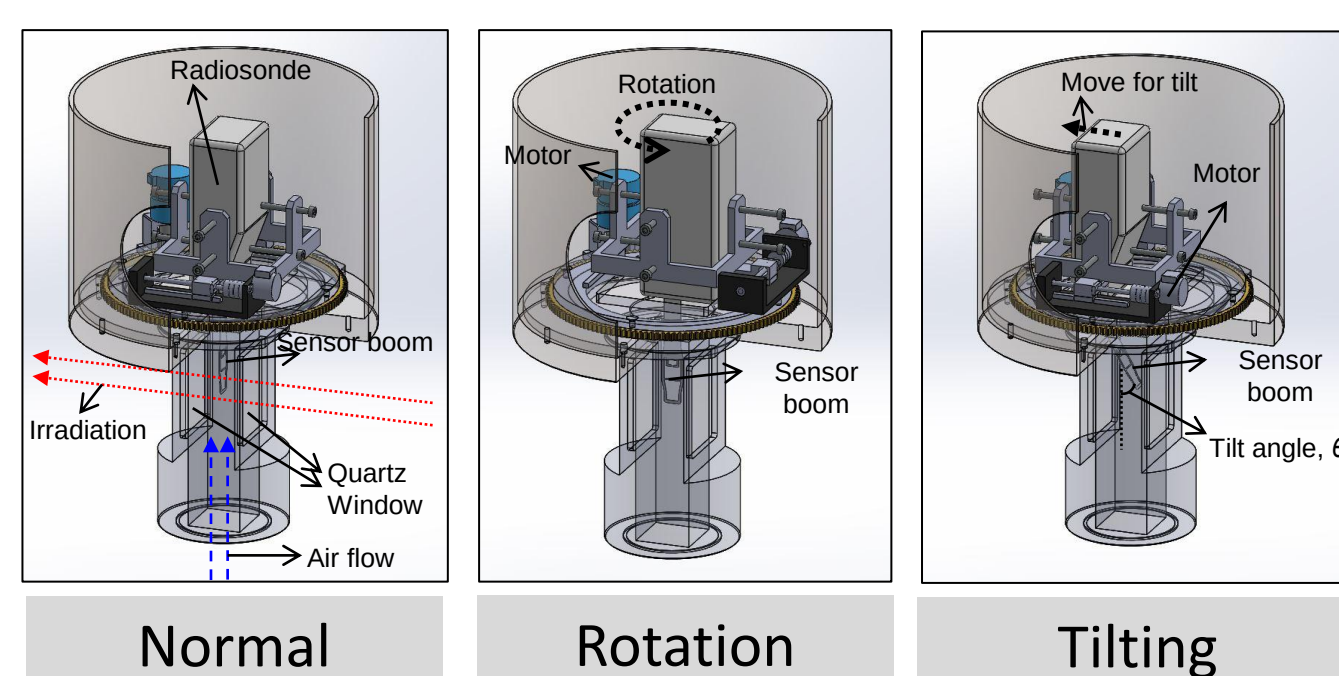
ECVs in Atmosphere, Land, and Ocean

Upper Air Simulator

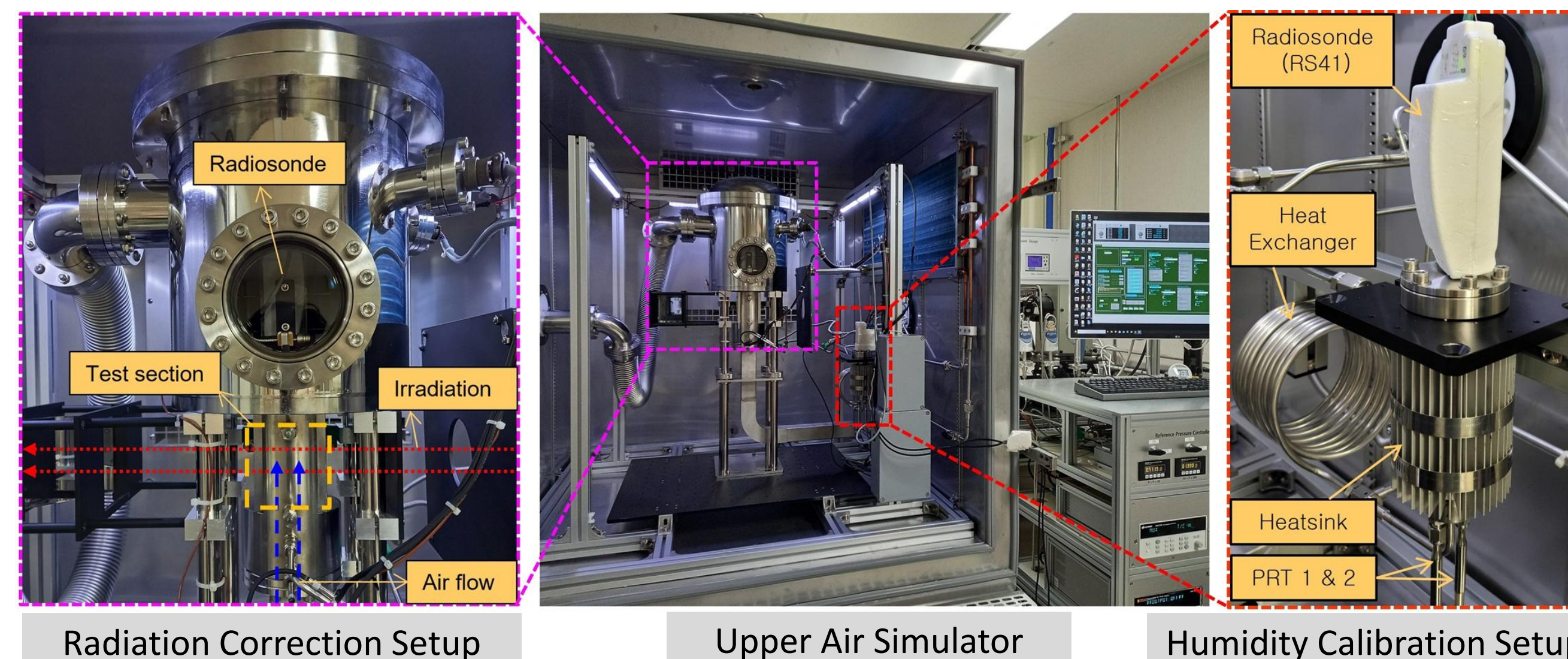
- Solar Radiation Correction of Radiosonde Temperature Sensors**
 - Temperature (-70–30 °C) by climate chamber
 - Air pressure (5–500 hPa) & ventilation (4–7 m/s) by sonic nozzles and vacuum pump
 - Irradiance (0–1500 W/m²) by solar simulator
- Calibration of Radiosonde Humidity Sensors**
 - Temperature (-70–20 °C) by climate chamber
 - Dew/Frostpoint temperature (-80–20 °C) by saturator-based dewpoint generator
 - Ventilation (5 m/s)
- Change of Geometry**
 - Radiosonde rotation (360°)
 - Boom tilting (0–45°)



Radiosounding



Normal Rotation Tilting

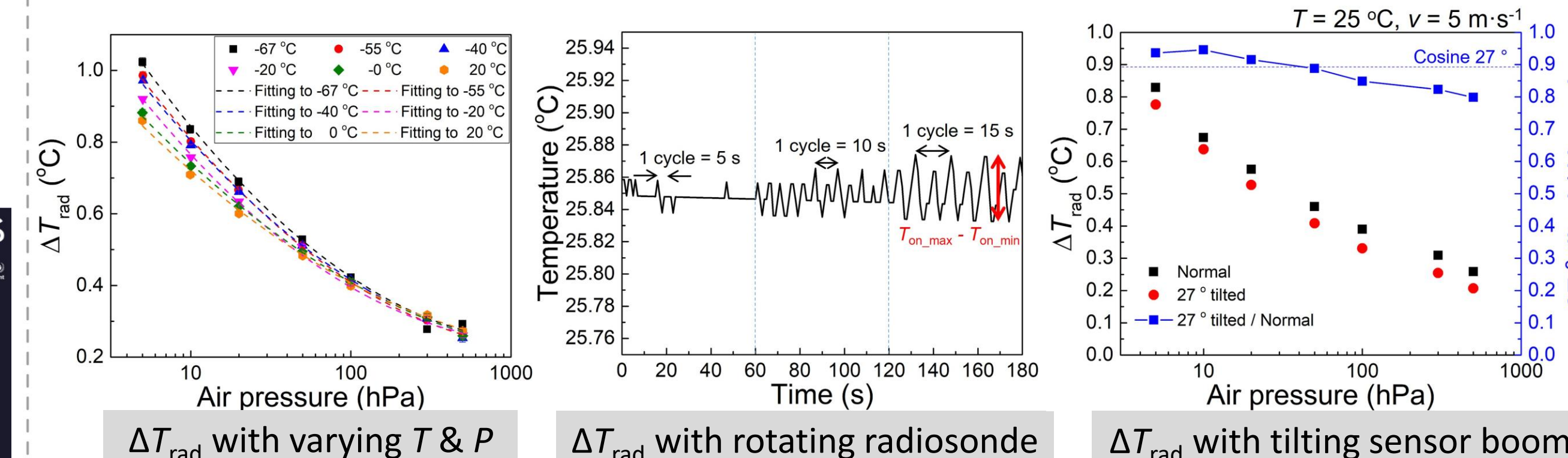


Radiation Correction Setup Upper Air Simulator Humidity Calibration Setup

Temperature, Humidity, & Irradiance in Upper Air

Solar Radiation Correction of Radiosonde Temperature Sensors

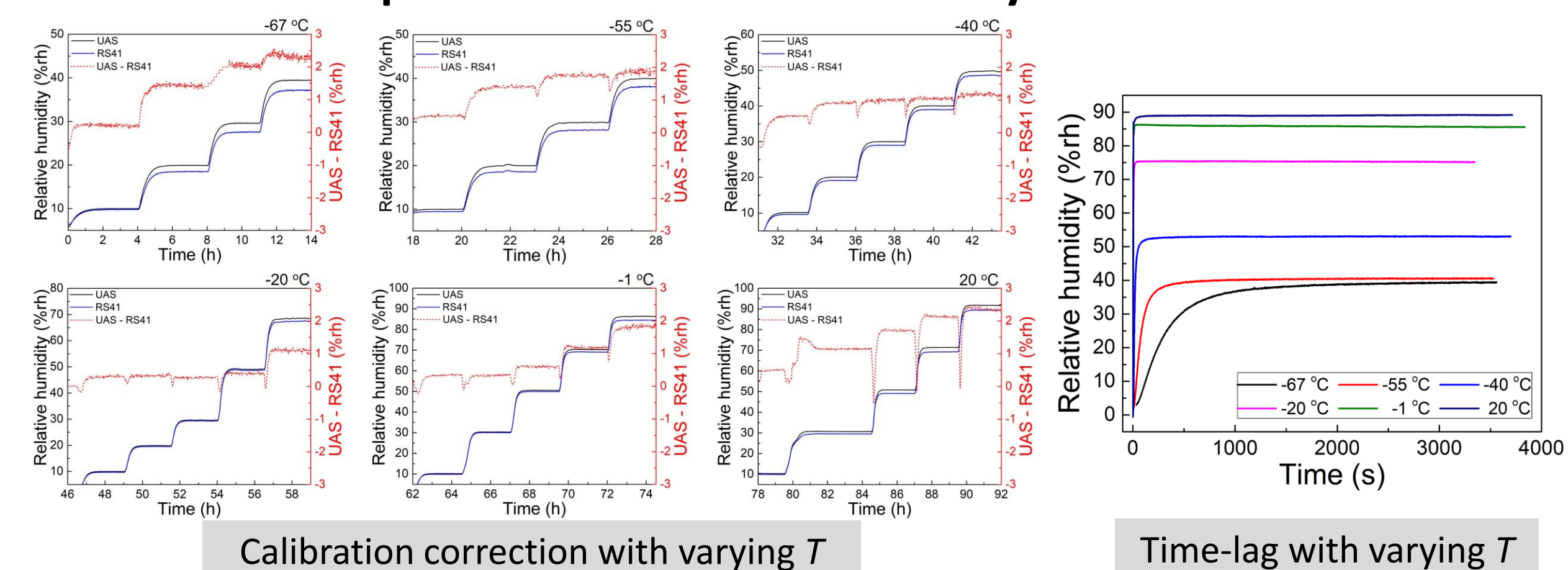
- Effective irradiance on the sensor is proportional to radiation correction (ΔT_{rad})
- Radiative heating of temperature sensors increases as pressure, temperature, and/or air ventilation decreases
- Radiosonde rotation and sensor boom tilt affect radiation correction



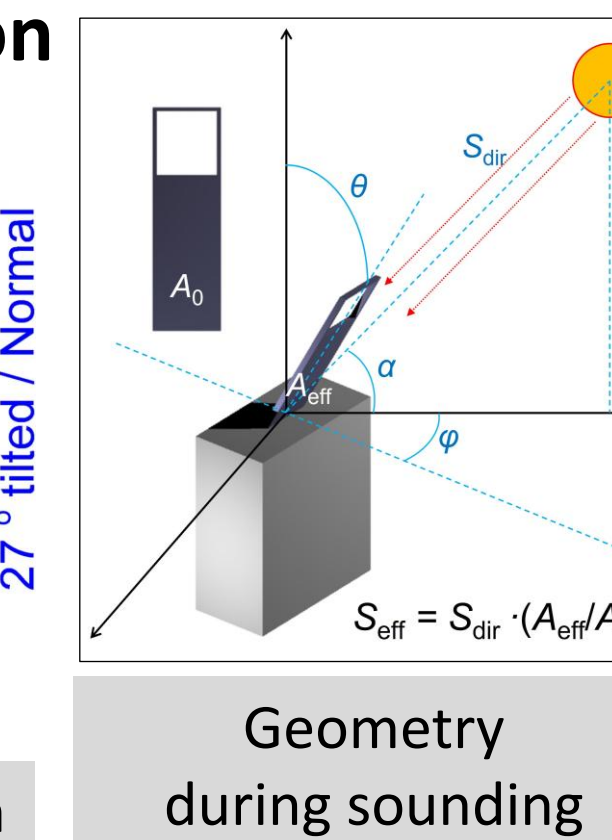
ΔT_{rad} with varying T & P ΔT_{rad} with rotating radiosonde ΔT_{rad} with tilting sensor boom

Calibration and Time-lag Correction of Radiosonde Humidity Sensors

- Effect of temperature on relative humidity sensors is evaluated



Calibration correction with varying T Time-lag with varying T



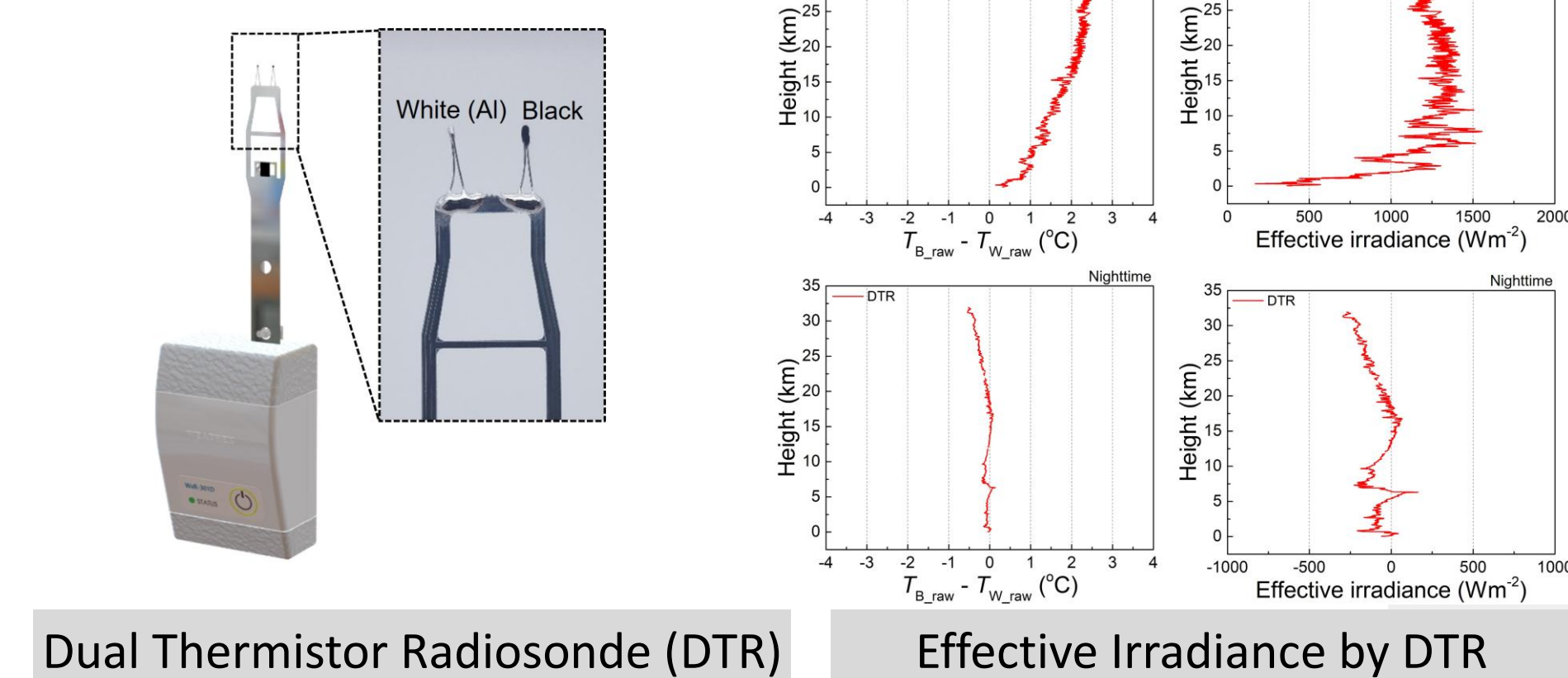
Geometry during sounding

Uncertainty factor	Condition	Unit	Standard uncertainty (k=1)	Contribution to uncertainty in radiation correction (k=2)
T	-67	°C	0.028	0.000 °C
P	5	hPa	0.01	0.000 °C
v	5	m s ⁻¹	0.058	0.004 °C
S	980	W m ⁻²	30.5	0.063 °C
Rotation	27	°	—	0.035 °C
Tilting	27	°	—	0.052 °C
Fitting error	-0.024 to 0.04	°C	0.023	0.046 °C
Expanded uncertainty in radiation correction (k=2)				0.100 °C

Uncertainty Budget on ΔT_{rad}

Measurement of Effective Solar Irradiance

- Dual Thermistor Radiosonde with Black & White Sensors → Irradiance



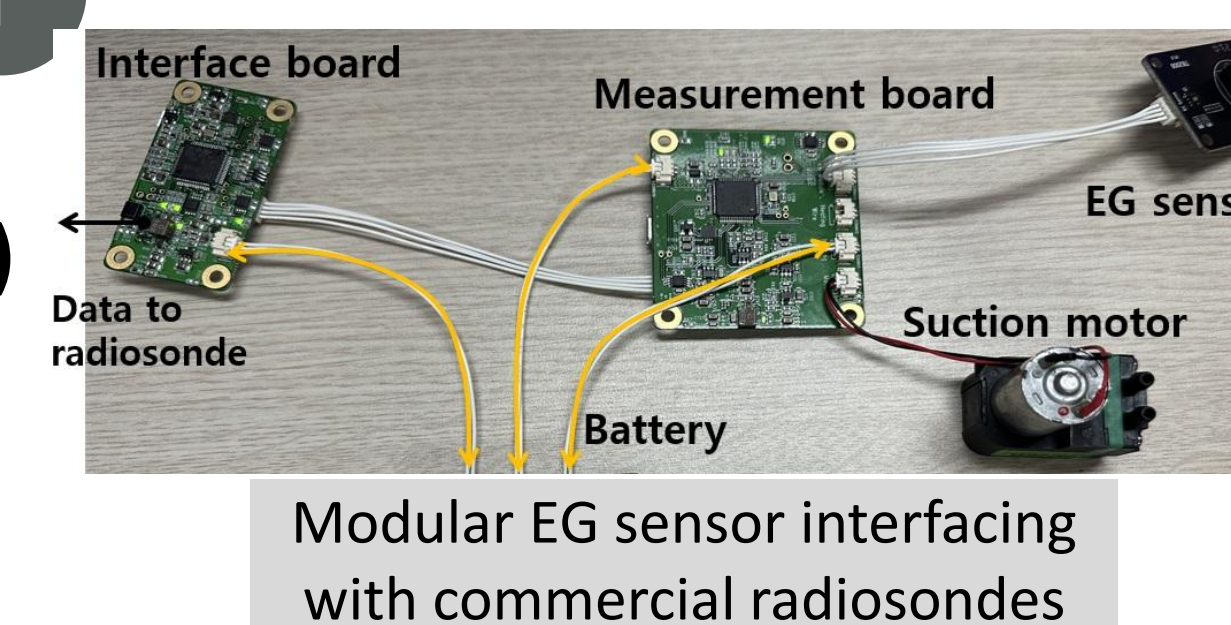
Dual Thermistor Radiosonde (DTR)

Effective Irradiance by DTR

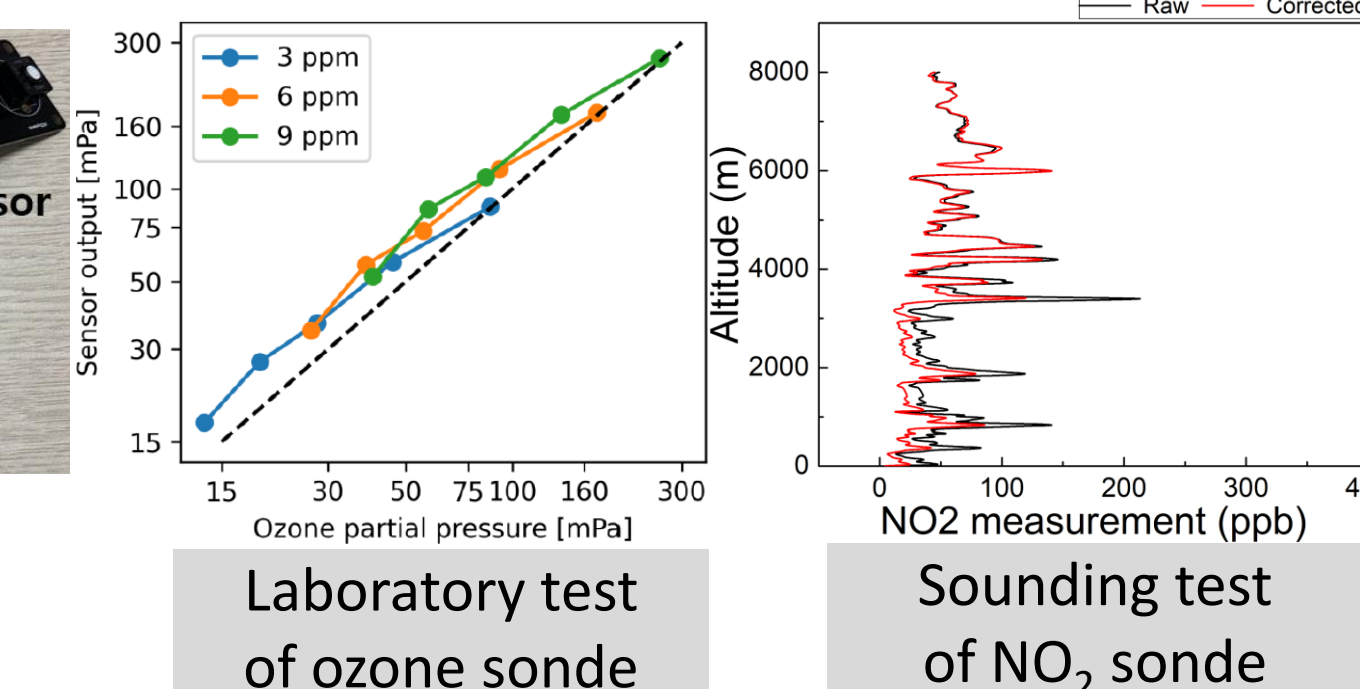
Environmental Gases (EG) in Upper Air

Small, lightweight modular NO₂ & ozone sondes

- Interface with radiosonde (Xdata transmission)
- Data acquisition using radiosonde receiver
- Laboratory test against EG gas standards
- Sounding tests



Modular EG sensor interfacing with commercial radiosondes



Laboratory test of ozone sonde

Sounding test of NO₂ sonde

Contribution to Other International Organizations

WMO (World Meteorological Organization)

- Participating in expert team on upper-air measurement to revise "Guide to Instruments and Methods of Observation"
- Collaboration with GCOS Reference Upper Air Network (GRUAN) to enhance SI traceability of radiosonde measurements

ISO (International Standard Organization)

- Three ISO standards for testing radiosonde temperature and humidity sensors are in Draft International Standard status

Conclusions

- KRISS has pioneered the development of the Upper Air Simulator (UAS) to replicate upper-atmosphere conditions to improve measurement traceability in upper air.
- Advancements in radiosonde sensors and environmental gas sensors will contribute to the global standardization.

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