

Calibration uncertainty

| Uncertainty contribution | °C |
|---|--------------|
| <i>Reference sensor calibration</i> | 0,020 |
| <i>Chamber uniformity</i> | 0,005 |
| <i>Sensor under calibration stability</i> | 0,009 |
| <i>Calibration curve</i> | 0,012 |
| Standard Uncertainty | 0,026 |
| Expanded Uncertainty (k=2) | 0,051 |

Difference vs T1 uncertainty

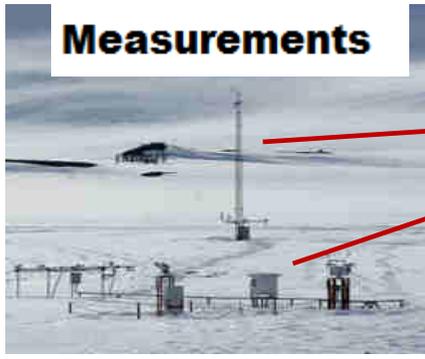
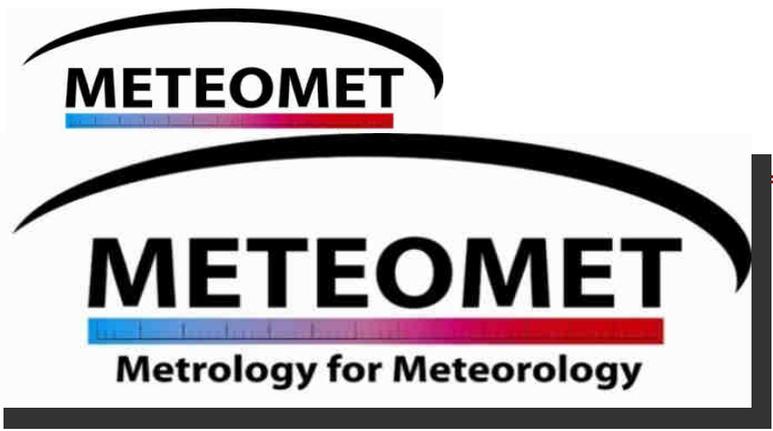
| Uncertainty contribution | °C |
|---|--------------|
| <i>T1 sensor stability</i> | 0,009 |
| <i>Chamber uniformity</i> | 0 |
| <i>Sensor under calibration stability</i> | 0,009 |
| <i>Calibration curve</i> | 0,014 |
| Standard Uncertainty | 0,019 |
| Expanded Uncertainty (k=2) | 0,038 |

Uncertainty on gradient in cct

| Uncertainty contribution | °C |
|-------------------------------------|--------------|
| <i>Relative correction curve t2</i> | 0,02 |
| <i>Relative correction curve t3</i> | 0,02 |
| <i>Relative correction curve t4</i> | 0,02 |
| <i>T1 sensor stability</i> | 0,009 |
| Standard Uncertainty | 0,036 |
| Expanded Uncertainty (k=2) | 0,072 |

Andrea Merlone

Metrology lab



le cnam

PTB Physikalisch Technische Bundesanstalt

CEM CENTRO ESPAÑOL DE METROLOGÍA

MIKES Centre for metrology and accreditation

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DANISH TECHNOLOGICAL INSTITUTE





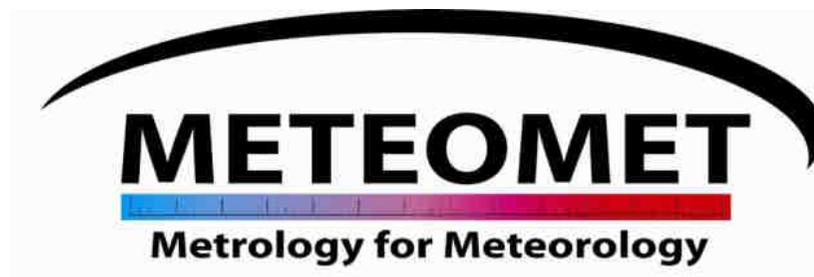
Permafrost boreholes

On site calibration at

Sommeiller pass

2015-2017

On site permafrost temperature sensors calibration



Laboratory calibration And system test



July 2017. A metrology lab at 3000 m



July 2017. A metrology lab at 3000 m



July 2017. A metrology lab at 3000 m



July 2017. A metrology lab at 3000 m

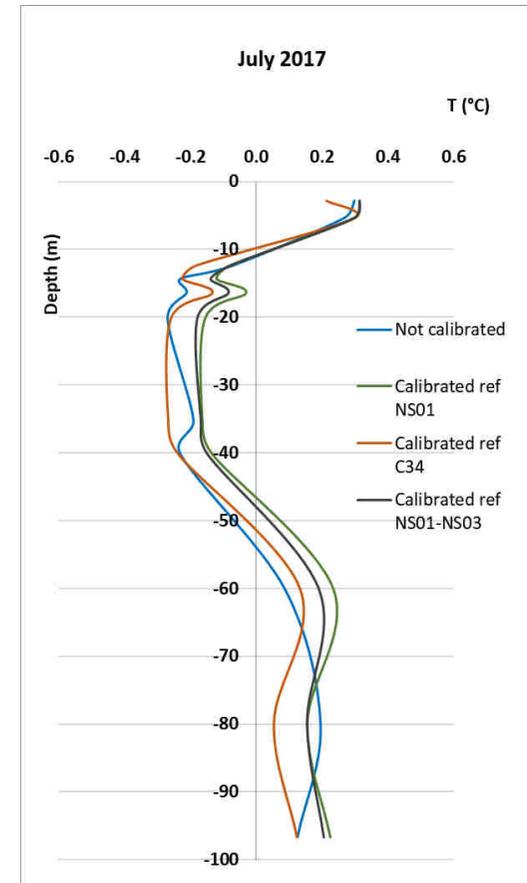
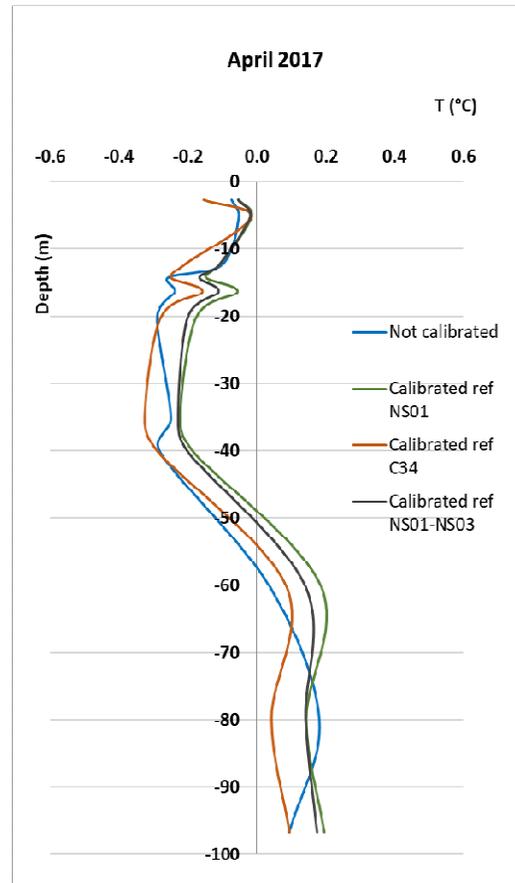
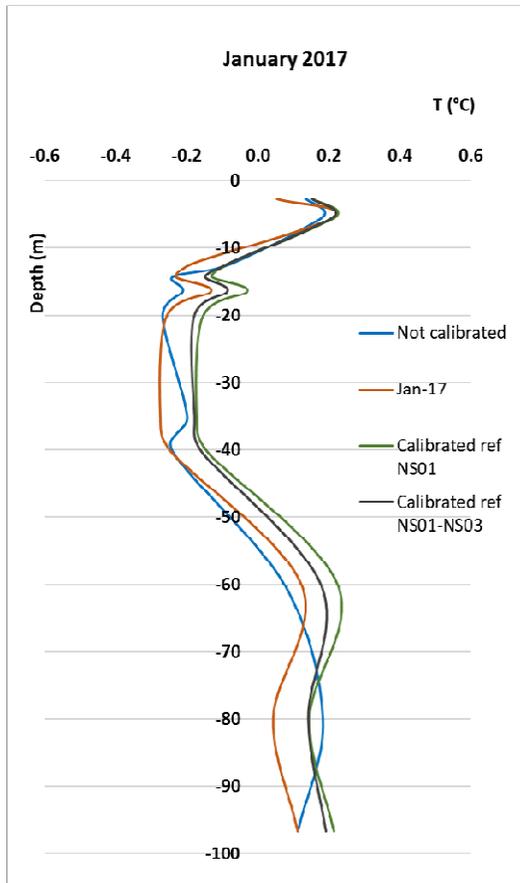


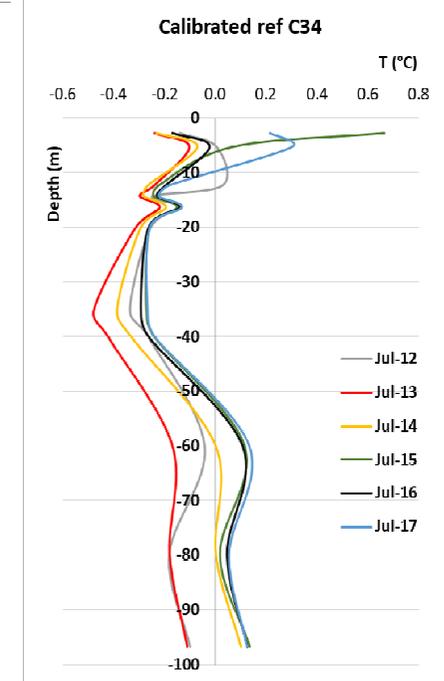
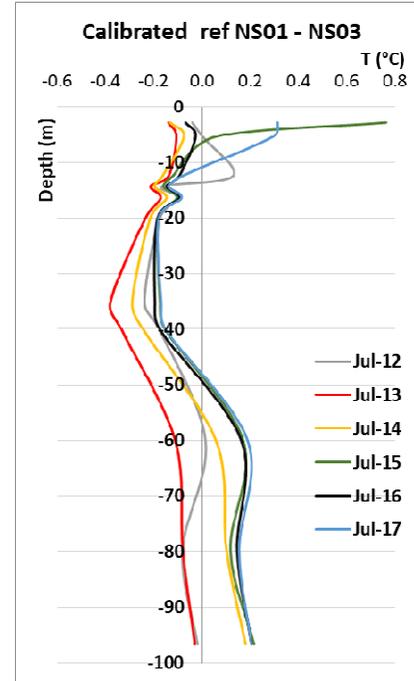
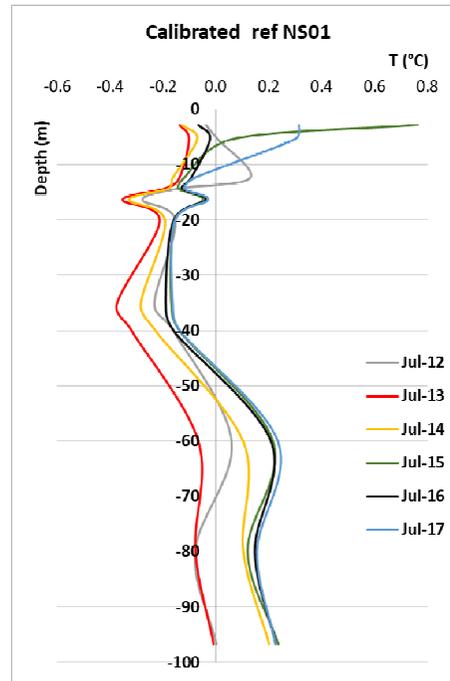
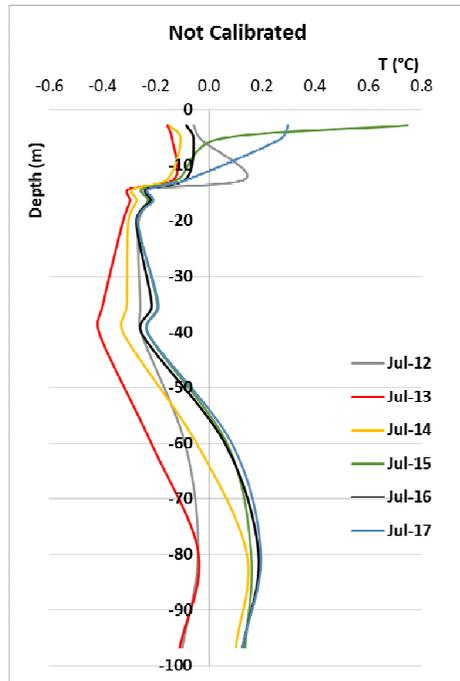
All sensors_2012-2017_pozzo100 - Excel

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V |
|-----|-----------|-------|-------|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-------|--------|--------|-------|-------|--------|-------|--------|-------|
| 1 | Depth (m) | | -2.8 | -5.35 | -12.35 | -14.3 | -15.2 | -16.35 | -17.35 | -18.2 | -20.2 | -22.2 | -25.2 | -27.2 | -30.3 | -35.2 | -40.2 | -50.2 | -60.15 | -70.5 | -79.9 | -89.8 |
| 246 | 21/01/12 | 13.00 | 0.201 | 0.258 | 0.525 | -0.247 | -0.199 | -0.199 | -0.247 | -0.189 | -0.256 | -0.17 | -0.247 | 0.201 | -0.208 | -0.247 | 0.096 | | -0.094 | | -0.046 | -0 |
| 247 | 21/01/12 | 14.00 | 0.202 | 0.259 | 0.525 | -0.237 | -0.189 | -0.208 | -0.246 | -0.189 | -0.256 | -0.17 | -0.246 | 0.202 | -0.208 | -0.246 | 0.097 | | -0.084 | | -0.046 | -0 |
| 248 | 21/01/12 | 15.00 | 0.192 | 0.259 | 0.525 | -0.265 | -0.208 | -0.208 | -0.246 | -0.189 | -0.256 | -0.17 | -0.246 | 0.192 | -0.199 | -0.237 | 0.268 | | -0.084 | | -0.056 | -0 |
| 249 | 21/01/12 | 16.00 | 0.191 | 0.258 | 0.524 | -0.238 | -0.199 | -0.199 | -0.247 | -0.199 | -0.257 | -0.171 | -0.247 | 0.201 | -0.209 | -0.247 | 0.22 | | -0.095 | | -0.056 | -0 |
| 250 | 21/01/12 | 17.00 | 0.192 | 0.259 | 0.525 | -0.237 | -0.199 | -0.218 | -0.246 | -0.199 | -0.256 | -0.17 | -0.256 | 0.192 | -0.208 | -0.246 | 0.173 | | -0.094 | | -0.056 | -0 |
| 251 | 21/01/12 | 18.00 | 0.191 | 0.258 | 0.525 | -0.237 | -0.199 | -0.199 | -0.247 | -0.19 | -0.257 | -0.171 | -0.247 | 0.201 | -0.209 | -0.247 | 0.153 | | -0.094 | | -0.056 | -0 |
| 252 | 21/01/12 | 19.00 | 0.201 | 0.258 | 0.525 | -0.237 | -0.199 | -0.209 | -0.237 | -0.199 | -0.256 | -0.17 | -0.256 | 0.192 | -0.209 | -0.247 | 0.154 | | -0.094 | | -0.056 | -0 |
| 253 | 21/01/12 | 20.00 | 0.192 | 0.249 | 0.525 | -0.247 | -0.199 | -0.209 | -0.237 | -0.199 | -0.256 | -0.171 | -0.247 | 0.201 | -0.209 | -0.247 | 0.172 | | -0.094 | | -0.056 | -0 |
| 254 | 21/01/12 | 21.00 | 0.2 | 0.247 | 0.523 | -0.239 | -0.2 | -0.2 | -0.239 | -0.2 | -0.258 | -0.172 | -0.258 | 0.19 | -0.21 | -0.248 | 0.143 | | -0.096 | | -0.057 | -0 |
| 255 | 21/01/12 | 22.00 | 0.192 | 0.259 | 0.525 | -0.237 | -0.199 | -0.199 | -0.246 | -0.199 | -0.256 | -0.161 | -0.256 | 0.192 | -0.208 | -0.246 | 0.125 | | -0.094 | | -0.046 | -0 |
| 256 | 21/01/12 | 23.00 | 0.182 | 0.248 | 0.524 | -0.238 | -0.2 | -0.209 | -0.247 | -0.2 | -0.257 | -0.171 | -0.257 | 0.191 | -0.209 | -0.247 | 0.124 | | -0.095 | | -0.057 | -0 |
| 257 | 22/01/12 | 0.00 | 0.191 | 0.248 | 0.505 | -0.276 | -0.209 | -0.105 | -0.219 | -0.2 | -0.257 | -0.171 | -0.257 | 0.191 | -0.209 | -0.057 | 0.115 | | -0.085 | | -0.066 | -0 |
| 258 | 22/01/12 | 1.00 | 0.192 | 0.249 | 0.515 | -0.247 | -0.209 | -0.199 | -0.247 | -0.199 | -0.256 | -0.161 | -0.256 | 0.192 | -0.209 | -0.247 | 0.134 | | -0.094 | | -0.056 | -0 |
| 259 | 22/01/12 | 2.00 | 0.182 | 0.248 | 0.515 | -0.247 | -0.199 | -0.199 | -0.247 | -0.199 | -0.257 | -0.18 | -0.257 | 0.191 | -0.209 | -0.247 | 0.134 | | -0.095 | | -0.047 | -0 |
| 260 | 22/01/12 | 3.00 | 0.192 | 0.25 | 0.516 | -0.236 | -0.198 | -0.208 | -0.256 | -0.189 | -0.256 | -0.17 | -0.256 | 0.192 | -0.208 | -0.246 | 0.126 | | -0.093 | | -0.055 | -0 |
| 261 | 22/01/12 | 4.00 | 0.196 | 0.253 | 0.52 | -0.233 | -0.195 | -0.204 | -0.242 | -0.195 | -0.252 | -0.166 | -0.252 | 0.196 | -0.204 | -0.242 | 0.129 | | -0.09 | | -0.052 | -0 |
| 262 | 22/01/12 | 5.00 | 0.188 | 0.255 | 0.522 | -0.26 | -0.202 | -0.193 | -0.24 | -0.183 | -0.26 | -0.164 | -0.25 | 0.198 | -0.202 | -0.25 | 0.131 | | -0.088 | | -0.059 | -0 |
| 263 | 22/01/12 | 6.00 | 0.179 | 0.255 | 0.531 | -0.259 | -0.202 | -0.202 | -0.24 | -0.183 | -0.259 | -0.164 | -0.25 | 0.189 | -0.202 | -0.24 | 0.122 | | -0.088 | | -0.059 | -0 |
| 264 | 22/01/12 | 7.00 | 0.188 | 0.254 | 0.521 | -0.298 | -0.212 | -0.203 | -0.251 | -0.184 | -0.26 | -0.174 | -0.251 | 0.197 | -0.203 | -0.241 | 0.14 | | -0.089 | | -0.06 | -0 |
| 265 | 22/01/12 | 8.00 | 0.179 | 0.246 | 0.522 | -0.24 | -0.202 | -0.202 | -0.25 | -0.193 | -0.259 | -0.173 | -0.25 | 0.198 | -0.212 | -0.24 | 0.122 | | -0.097 | | -0.05 | -0 |
| 266 | 22/01/12 | 9.00 | 0.188 | 0.246 | 0.522 | -0.24 | -0.193 | -0.202 | -0.25 | -0.193 | -0.26 | -0.174 | -0.25 | 0.188 | -0.202 | -0.25 | 0.131 | | -0.097 | | -0.05 | -0 |
| 267 | 22/01/12 | 10.00 | 0.188 | 0.245 | 0.521 | -0.251 | -0.203 | -0.203 | -0.251 | -0.194 | -0.26 | -0.174 | -0.251 | 0.188 | -0.203 | -0.251 | 0.121 | | -0.098 | | -0.051 | -0 |
| 268 | 22/01/12 | 11.00 | 0.189 | 0.246 | 0.522 | -0.24 | -0.193 | -0.202 | -0.25 | -0.193 | -0.25 | -0.174 | -0.25 | 0.189 | -0.202 | -0.24 | 0.122 | | -0.088 | | -0.05 | -0 |
| 269 | 22/01/12 | 12.00 | 0.192 | 0.249 | 0.525 | -0.246 | -0.199 | -0.208 | -0.246 | -0.199 | -0.256 | -0.17 | -0.246 | 0.182 | -0.199 | -0.237 | 0.116 | | -0.094 | | -0.056 | -0 |
| 270 | 22/01/12 | 13.00 | 0.191 | 0.249 | 0.525 | -0.228 | -0.19 | -0.209 | -0.237 | -0.19 | -0.256 | -0.171 | -0.247 | 0.191 | -0.199 | -0.237 | 0.115 | | -0.085 | | -0.047 | -0 |
| 271 | 22/01/12 | 14.00 | 0.183 | 0.24 | 0.525 | -0.236 | -0.198 | -0.198 | -0.246 | -0.198 | -0.256 | -0.16 | -0.246 | 0.192 | -0.208 | -0.246 | 0.116 | | -0.093 | | -0.046 | -0 |
| 272 | 22/01/12 | 15.00 | 0.182 | 0.239 | 0.525 | -0.237 | -0.199 | -0.209 | -0.237 | -0.199 | -0.256 | -0.161 | -0.247 | 0.182 | -0.209 | -0.247 | 0.115 | | -0.094 | | -0.056 | -0 |
| 273 | 22/01/12 | 16.00 | 0.182 | 0.239 | 0.524 | -0.238 | -0.199 | -0.209 | -0.238 | -0.199 | -0.257 | -0.161 | -0.247 | 0.191 | -0.209 | -0.247 | 0.105 | | -0.095 | | -0.056 | -0 |
| 274 | 22/01/12 | 17.00 | 0.186 | 0.243 | 0.519 | -0.233 | -0.195 | -0.205 | -0.252 | -0.195 | -0.262 | -0.176 | -0.252 | 0.186 | -0.205 | -0.243 | 0.11 | | -0.09 | | -0.052 | -0 |
| 275 | 22/01/12 | 18.00 | 0.183 | 0.24 | 0.516 | -0.246 | -0.198 | -0.208 | -0.255 | -0.198 | -0.255 | -0.179 | -0.255 | 0.183 | -0.208 | -0.246 | 0.107 | | -0.093 | | -0.055 | -0 |
| 276 | 22/01/12 | 19.00 | 0.179 | 0.245 | 0.521 | -0.25 | -0.203 | -0.203 | -0.25 | -0.193 | -0.26 | -0.174 | -0.25 | 0.179 | -0.203 | -0.241 | 0.112 | | -0.098 | | -0.05 | -0 |
| 277 | 22/01/12 | 20.00 | 0.178 | 0.245 | 0.521 | -0.25 | -0.203 | -0.203 | -0.25 | -0.193 | -0.26 | -0.174 | -0.25 | 0.178 | -0.203 | -0.241 | 0.107 | | -0.098 | | -0.05 | -0 |

All sensors_2012-2017_pozzo100 - Excel

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V |
|-----|-----------|-------|-------|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-------|--------|--------|-------|-------|--------|-------|--------|-------|
| 1 | Depth (m) | | -2.8 | -5.35 | -12.35 | -14.3 | -15.2 | -16.35 | -17.35 | -18.2 | -20.2 | -22.2 | -25.2 | -27.2 | -30.3 | -35.2 | -40.2 | -50.2 | -60.15 | -70.5 | -79.9 | -89.8 |
| 246 | 21/01/12 | 13.00 | 0.201 | 0.258 | 0.525 | -0.247 | -0.199 | -0.199 | -0.247 | -0.189 | -0.256 | -0.17 | -0.247 | 0.201 | -0.208 | -0.247 | 0.096 | | -0.094 | | -0.046 | -0 |
| 247 | 21/01/12 | 14.00 | 0.202 | 0.259 | 0.525 | -0.237 | -0.189 | -0.208 | -0.246 | -0.189 | -0.256 | -0.17 | -0.246 | 0.202 | -0.208 | -0.246 | 0.097 | | -0.084 | | -0.046 | -0 |
| 248 | 21/01/12 | 15.00 | 0.192 | 0.259 | 0.525 | -0.265 | -0.208 | -0.208 | -0.246 | -0.189 | -0.256 | -0.17 | -0.246 | 0.192 | -0.199 | -0.237 | 0.268 | | -0.084 | | -0.056 | -0 |
| 249 | 21/01/12 | 16.00 | 0.191 | 0.258 | 0.524 | -0.238 | -0.199 | -0.199 | -0.247 | -0.199 | -0.257 | -0.171 | -0.247 | 0.201 | -0.209 | -0.247 | 0.22 | | -0.095 | | -0.056 | -0 |
| 250 | 21/01/12 | 17.00 | 0.192 | 0.259 | 0.525 | -0.237 | -0.199 | -0.218 | -0.246 | -0.199 | -0.256 | -0.17 | -0.256 | 0.192 | -0.208 | -0.246 | 0.173 | | -0.094 | | -0.056 | -0 |
| 251 | 21/01/12 | 18.00 | 0.191 | 0.258 | 0.525 | -0.237 | -0.199 | -0.199 | -0.247 | -0.19 | -0.257 | -0.171 | -0.247 | 0.201 | -0.209 | -0.247 | 0.153 | | -0.094 | | -0.056 | -0 |
| 252 | 21/01/12 | 19.00 | 0.201 | 0.258 | 0.525 | -0.237 | -0.199 | -0.209 | -0.237 | -0.199 | -0.256 | -0.17 | -0.256 | 0.192 | -0.209 | -0.247 | 0.154 | | -0.094 | | -0.056 | -0 |
| 253 | 21/01/12 | 20.00 | 0.192 | 0.249 | 0.525 | -0.247 | -0.199 | -0.209 | -0.237 | -0.199 | -0.256 | -0.171 | -0.247 | 0.201 | -0.209 | -0.247 | 0.172 | | -0.094 | | -0.056 | -0 |
| 254 | 21/01/12 | 21.00 | 0.2 | 0.247 | 0.523 | -0.239 | -0.2 | -0.2 | -0.239 | -0.2 | -0.258 | -0.172 | -0.258 | 0.19 | -0.21 | -0.248 | 0.143 | | -0.096 | | -0.057 | -0 |
| 255 | 21/01/12 | 22.00 | 0.192 | 0.259 | 0.525 | -0.237 | -0.199 | -0.199 | -0.246 | -0.199 | -0.256 | -0.161 | -0.256 | 0.192 | -0.208 | -0.246 | 0.125 | | -0.094 | | -0.046 | -0 |
| 256 | 21/01/12 | 23.00 | 0.182 | 0.248 | 0.524 | -0.238 | -0.2 | -0.209 | -0.247 | -0.2 | -0.257 | -0.171 | -0.257 | 0.191 | -0.209 | -0.247 | 0.124 | | -0.095 | | -0.057 | -0 |
| 257 | 22/01/12 | 0.00 | 0.191 | 0.248 | 0.505 | -0.276 | -0.209 | 0.105 | -0.219 | -0.2 | -0.257 | -0.171 | -0.257 | 0.191 | -0.209 | -0.057 | 0.115 | | -0.085 | | -0.066 | -0 |
| 258 | 22/01/12 | 1.00 | 0.192 | 0.249 | 0.515 | -0.247 | -0.209 | -0.199 | -0.247 | -0.199 | -0.256 | -0.161 | -0.256 | 0.192 | -0.209 | -0.247 | 0.134 | | -0.094 | | -0.056 | -0 |
| 259 | 22/01/12 | 2.00 | 0.182 | 0.248 | 0.515 | -0.247 | -0.199 | -0.199 | -0.247 | -0.199 | -0.257 | -0.18 | -0.257 | 0.191 | -0.209 | -0.247 | 0.134 | | -0.095 | | -0.047 | -0 |
| 260 | 22/01/12 | 3.00 | 0.192 | 0.25 | 0.516 | -0.236 | -0.198 | -0.208 | -0.256 | -0.189 | -0.256 | -0.17 | -0.256 | 0.192 | -0.208 | -0.246 | 0.126 | | -0.093 | | -0.055 | -0 |
| 261 | 22/01/12 | 4.00 | 0.196 | 0.253 | 0.52 | -0.233 | -0.195 | -0.204 | -0.242 | -0.195 | -0.252 | -0.166 | -0.252 | 0.196 | -0.204 | -0.242 | 0.129 | | -0.09 | | -0.052 | -0 |
| 262 | 22/01/12 | 5.00 | 0.188 | 0.255 | 0.522 | -0.26 | -0.202 | -0.193 | -0.24 | -0.183 | -0.26 | -0.164 | -0.25 | 0.198 | -0.202 | -0.25 | 0.131 | | -0.088 | | -0.059 | -0 |
| 263 | 22/01/12 | 6.00 | 0.179 | 0.255 | 0.531 | -0.259 | -0.202 | -0.202 | -0.24 | -0.183 | -0.259 | -0.164 | -0.25 | 0.189 | -0.202 | -0.24 | 0.122 | | -0.088 | | -0.059 | -0 |
| 264 | 22/01/12 | 7.00 | 0.188 | 0.254 | 0.521 | -0.298 | -0.212 | -0.203 | -0.251 | -0.184 | -0.26 | -0.174 | -0.251 | 0.197 | -0.203 | -0.241 | 0.14 | | -0.089 | | -0.06 | -0 |
| 265 | 22/01/12 | 8.00 | 0.179 | 0.246 | 0.522 | -0.24 | -0.202 | -0.202 | -0.25 | -0.193 | -0.259 | -0.173 | -0.25 | 0.198 | -0.212 | -0.24 | 0.122 | | -0.097 | | -0.05 | -0 |
| 266 | 22/01/12 | 9.00 | 0.188 | 0.246 | 0.522 | -0.24 | -0.193 | -0.202 | -0.25 | -0.193 | -0.26 | -0.174 | -0.25 | 0.188 | -0.202 | -0.25 | 0.131 | | -0.097 | | -0.05 | -0 |
| 267 | 22/01/12 | 10.00 | 0.188 | 0.245 | 0.521 | -0.251 | -0.203 | -0.203 | -0.251 | -0.194 | -0.26 | -0.174 | -0.251 | 0.188 | -0.203 | -0.251 | 0.121 | | -0.098 | | -0.051 | -0 |
| 268 | 22/01/12 | 11.00 | 0.189 | 0.246 | 0.522 | -0.24 | -0.193 | -0.202 | -0.25 | -0.193 | -0.25 | -0.174 | -0.25 | 0.189 | -0.202 | -0.24 | 0.122 | | -0.088 | | -0.05 | -0 |
| 269 | 22/01/12 | 12.00 | 0.192 | 0.249 | 0.525 | -0.246 | -0.199 | -0.208 | -0.246 | -0.199 | -0.256 | -0.17 | -0.246 | 0.182 | -0.199 | -0.237 | 0.116 | | -0.094 | | -0.056 | -0 |
| 270 | 22/01/12 | 13.00 | 0.191 | 0.249 | 0.525 | -0.228 | -0.19 | -0.209 | -0.237 | -0.19 | -0.256 | -0.171 | -0.247 | 0.191 | -0.199 | -0.237 | 0.115 | | -0.085 | | -0.047 | -0 |
| 271 | 22/01/12 | 14.00 | 0.183 | 0.24 | 0.525 | -0.236 | -0.198 | -0.198 | -0.246 | -0.198 | -0.256 | -0.16 | -0.246 | 0.192 | -0.208 | -0.246 | 0.116 | | -0.093 | | -0.046 | -0 |
| 272 | 22/01/12 | 15.00 | 0.182 | 0.239 | 0.525 | -0.237 | -0.199 | -0.209 | -0.237 | -0.199 | -0.256 | -0.161 | -0.247 | 0.182 | -0.209 | -0.247 | 0.115 | | -0.094 | | -0.056 | -0 |
| 273 | 22/01/12 | 16.00 | 0.182 | 0.239 | 0.524 | -0.238 | -0.199 | -0.209 | -0.238 | -0.199 | -0.257 | -0.161 | -0.247 | 0.191 | -0.209 | -0.247 | 0.105 | | -0.095 | | -0.056 | -0 |
| 274 | 22/01/12 | 17.00 | 0.186 | 0.243 | 0.519 | -0.233 | -0.195 | -0.205 | -0.252 | -0.195 | -0.262 | -0.176 | -0.252 | 0.186 | -0.205 | -0.243 | 0.11 | | -0.09 | | -0.052 | -0 |
| 275 | 22/01/12 | 18.00 | 0.183 | 0.24 | 0.516 | -0.246 | -0.198 | -0.208 | -0.255 | -0.198 | -0.255 | -0.179 | -0.255 | 0.183 | -0.208 | -0.246 | 0.107 | | -0.093 | | -0.055 | -0 |
| 276 | 22/01/12 | 19.00 | 0.179 | 0.245 | 0.521 | -0.25 | -0.203 | -0.203 | -0.25 | -0.193 | -0.26 | -0.174 | -0.25 | 0.179 | -0.203 | -0.241 | 0.112 | | -0.098 | | -0.05 | -0 |
| 277 | 22/01/12 | 20.00 | 0.178 | 0.245 | 0.521 | -0.251 | -0.203 | -0.203 | -0.251 | -0.193 | -0.26 | -0.174 | -0.251 | 0.178 | -0.203 | -0.241 | 0.107 | | -0.098 | | -0.05 | -0 |



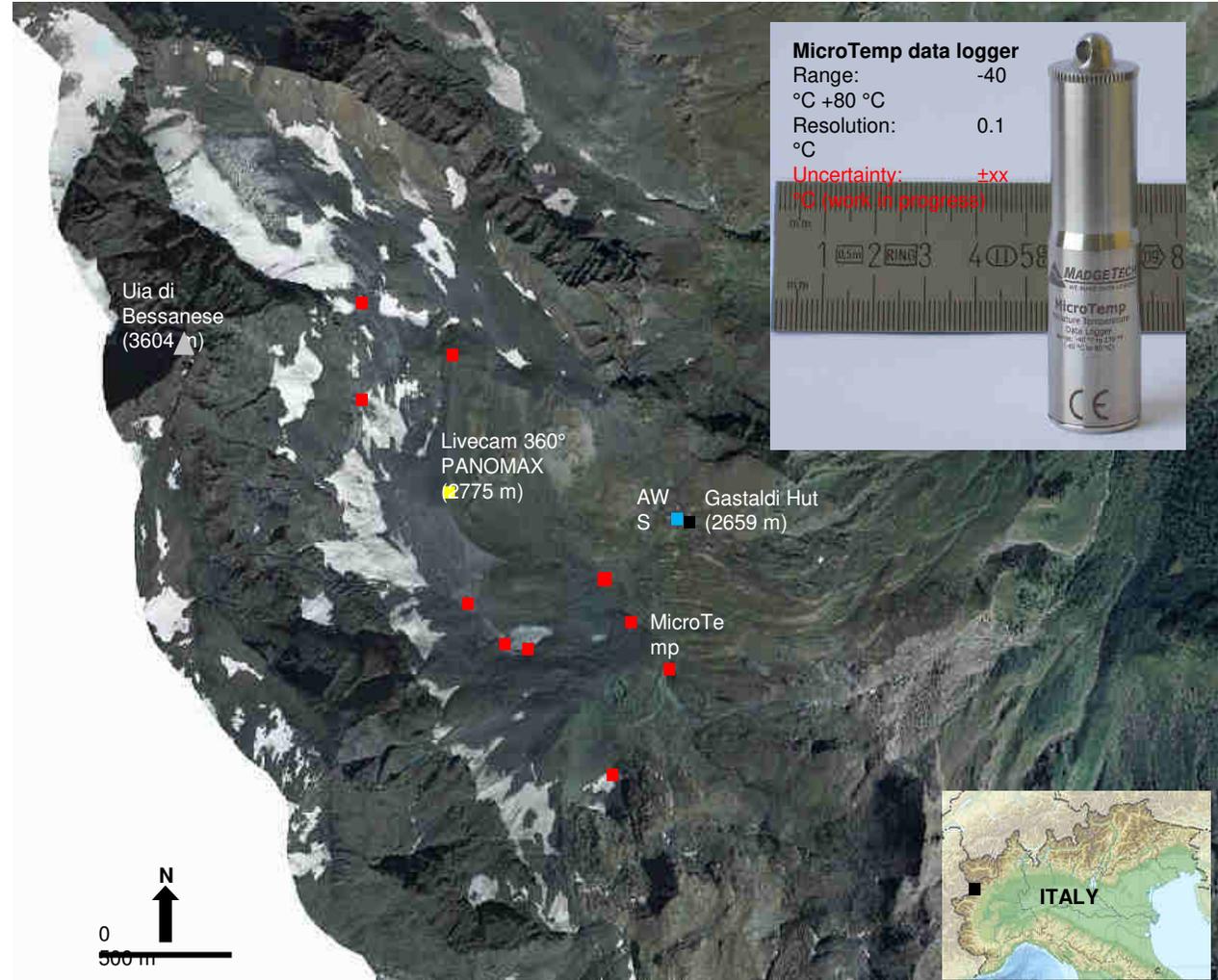


RIST project

The «RiST Project: Scientific and Technological Research at the Bessanese glacial basin»



Base map: ortophoto 2010, Regione Piemonte

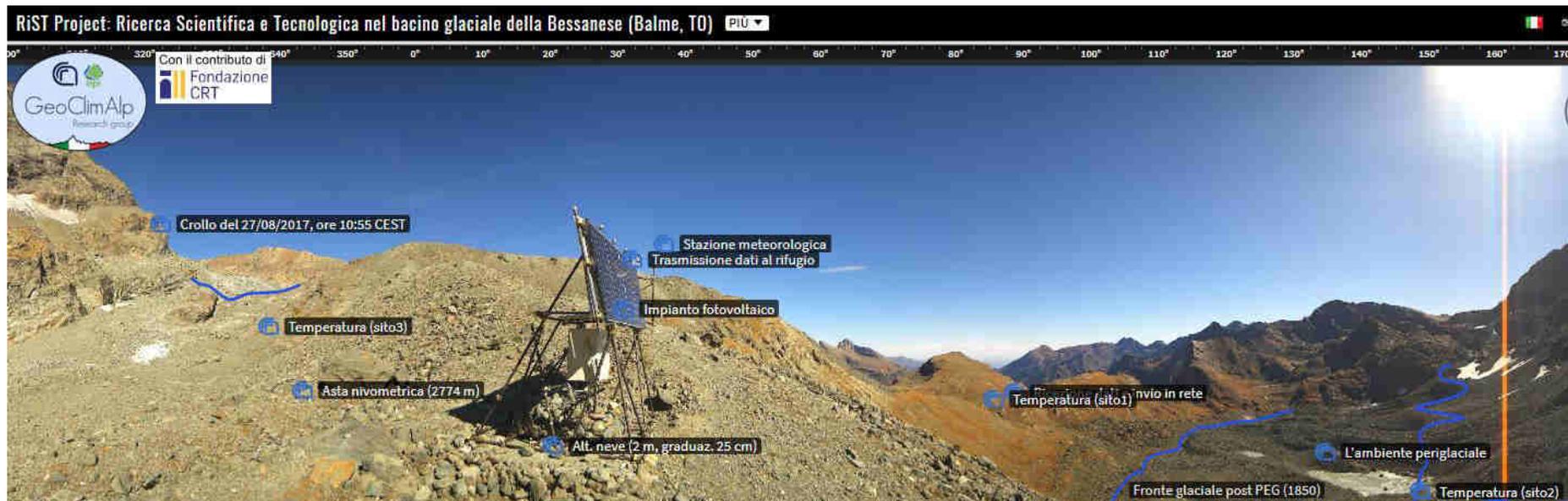


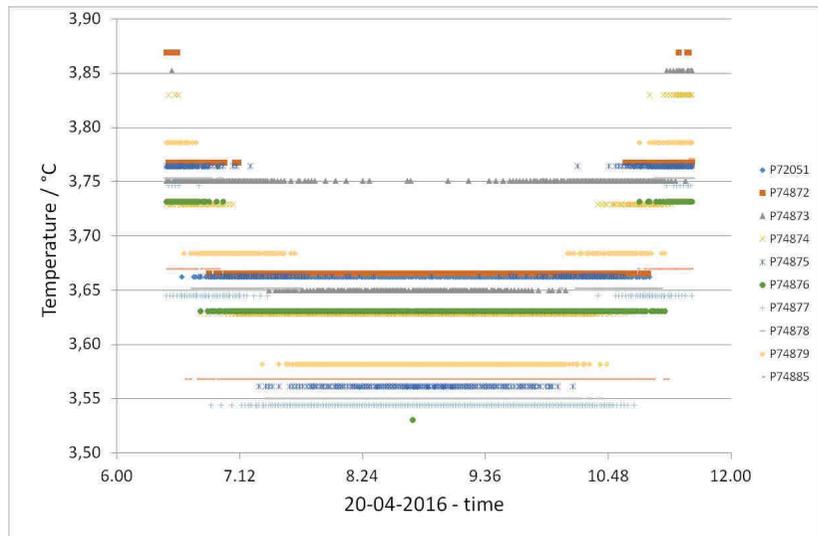
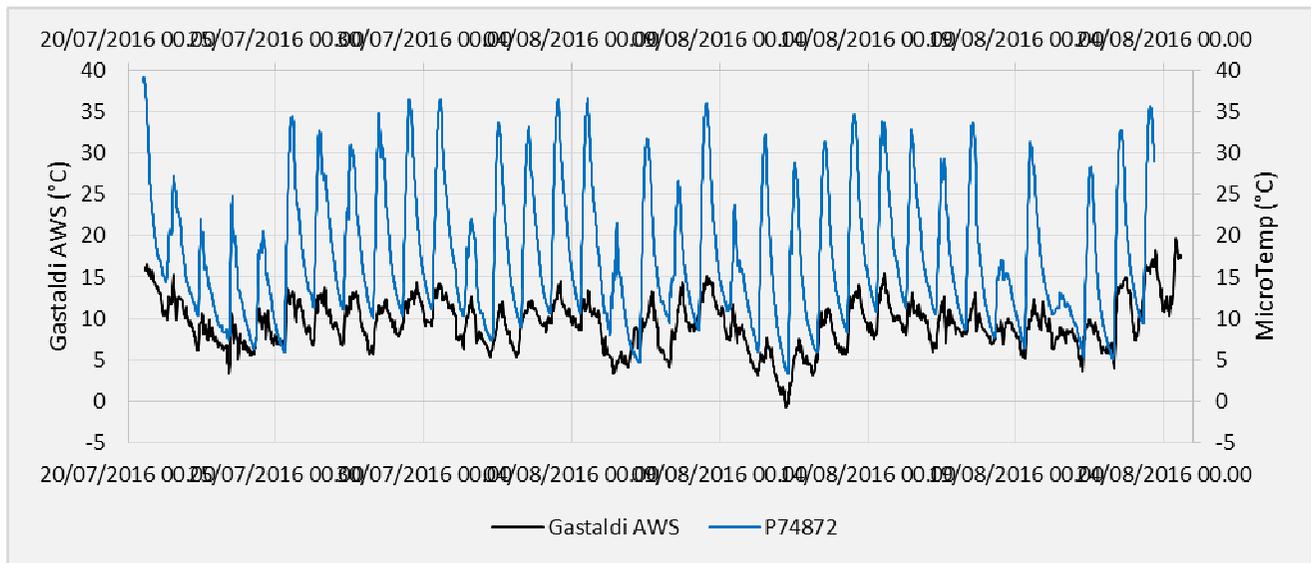
Realizzazione di un sito per messa a punto di misure di riferimento in ambiente glaciale e periglaciale

Valutazione di incertezze di misura

Studio parametri di significatività dei dati e confrontabilità

Promozione di un sito per “turismo scientifico”





Snow albedo as uncertainty on near surface air temperature measurements

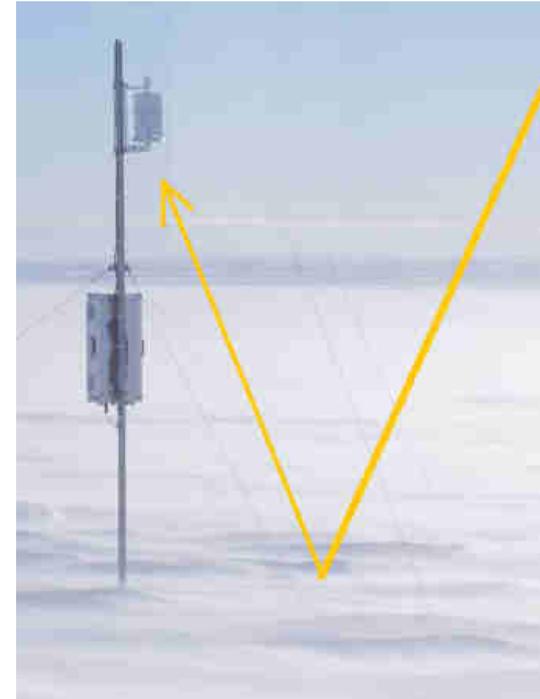
High mountains observations: permafrost and albedo (INRIM, BEV)

Air temperature instruments are affected by radiative extra heating when exposed to snow covered surface .

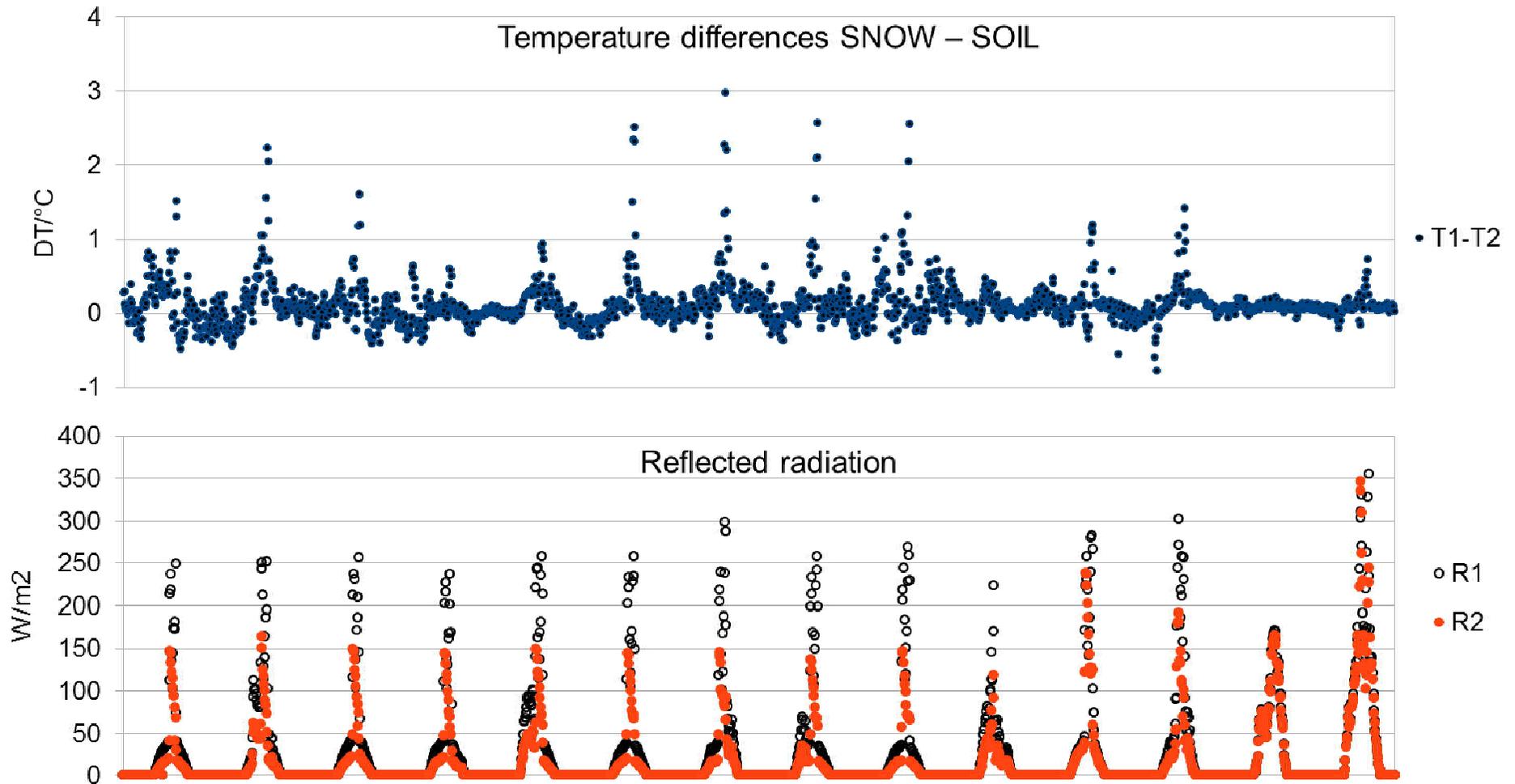
Temperature records can be different from air temperature value, due to warming of sensor by conduction and convection, inside the shields.

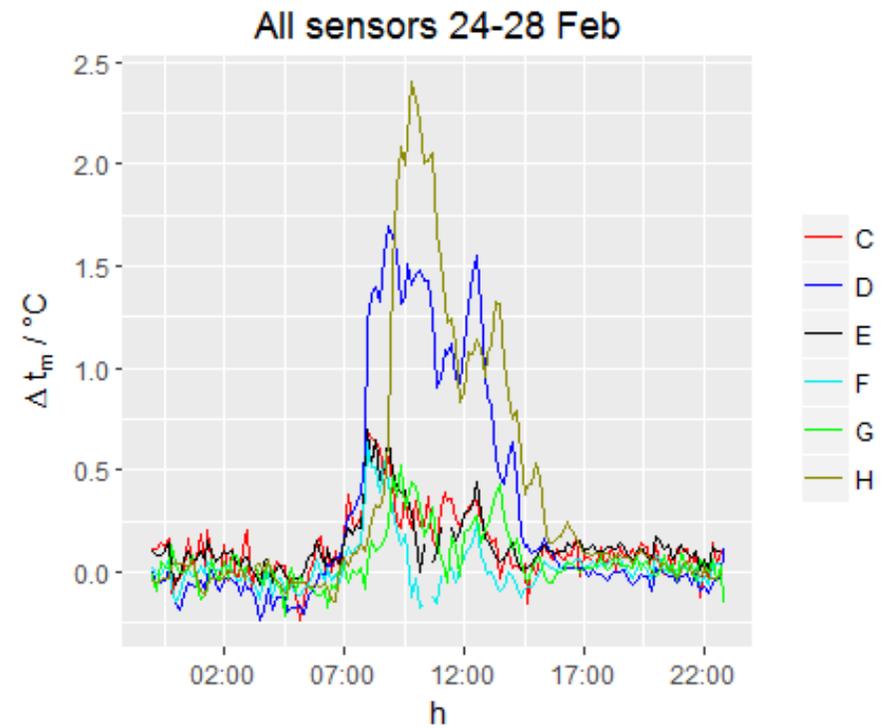
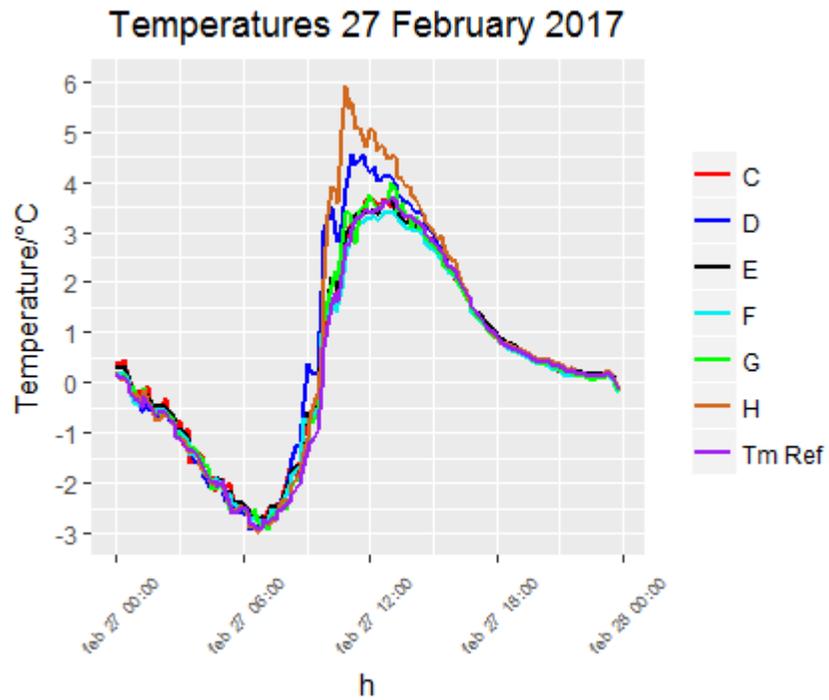
Different instrument show different magnitude of this effect. The evaluation of this effect, in terms of correction and/or uncertainty on air temperature measurements is the **scope of this work**.

Method: evaluation of the difference between the readings of couples of identical sensors exposed to snow covered surface or to natural soil, in the same site.



Preliminary results





2) Collection of instruments from manufacturers

Six manufacturers agreed to take part in the experiment, sending couples of identical sensors, shields and loggers.

Different solutions were considered to cover most commonly used devices.

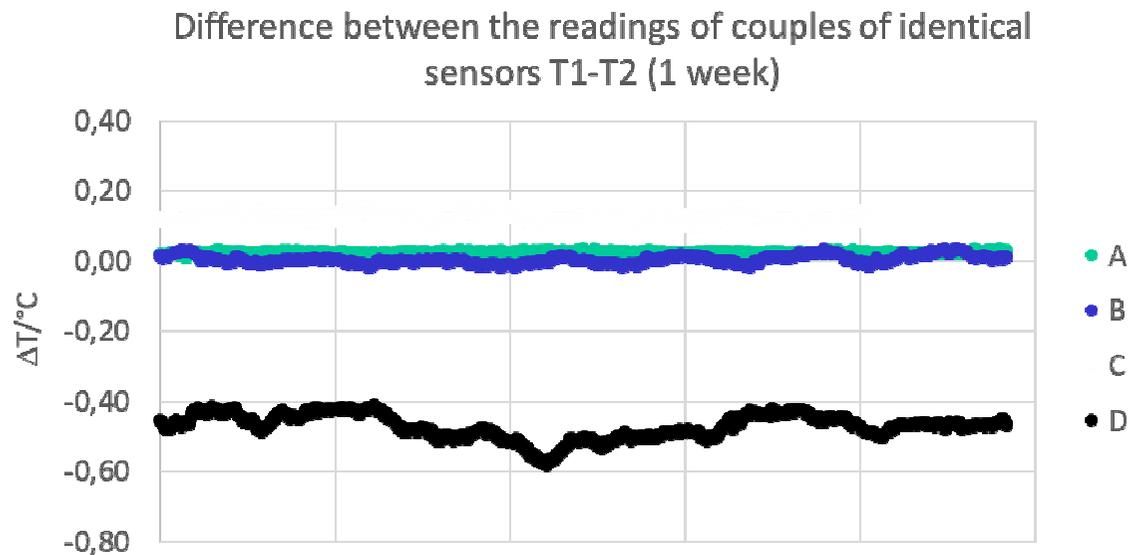
Each participant was requested to also provide at least one extra sensors wind speed and direction, thermo hygrometer, albedometers, ...



3) Laboratory characterisation of sensors and complete systems

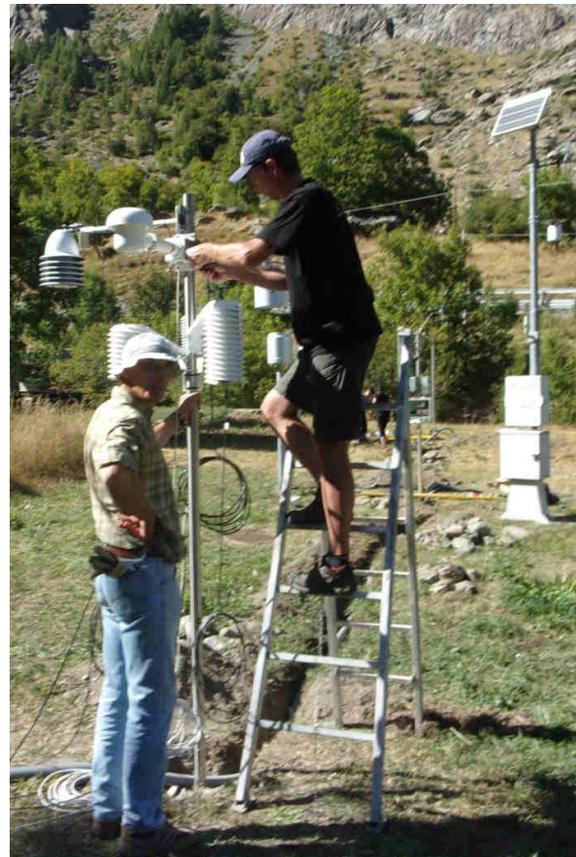
Study of the different dataloggers,
evaluation of best mounting solutions.

Evaluations of difference between couples
of sensors, including shields, in a controlled
environment with slow temperature change.



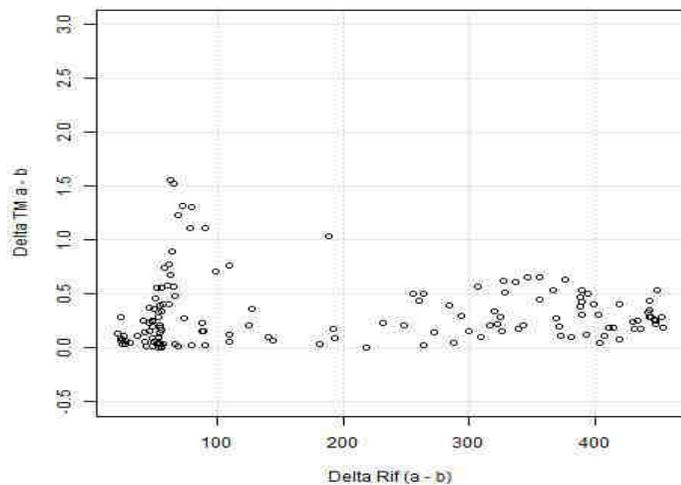
Climate Data Quality Lab at IRPI

An example: the albedo effect on air T values

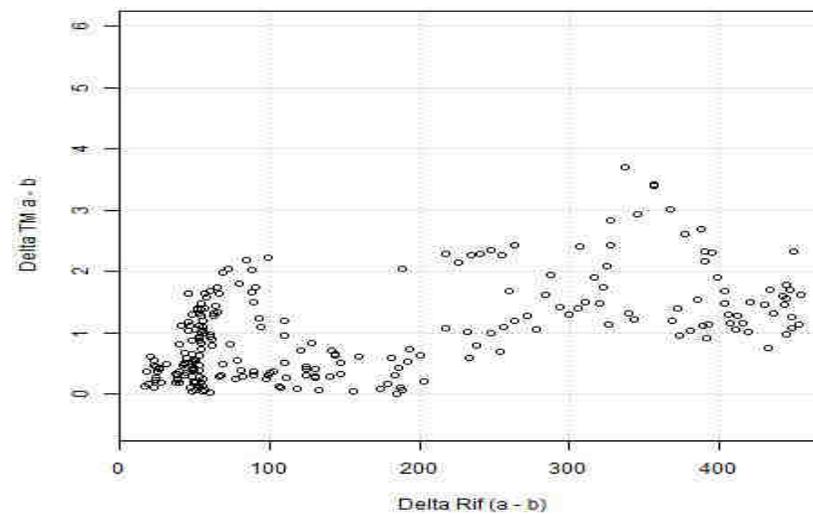




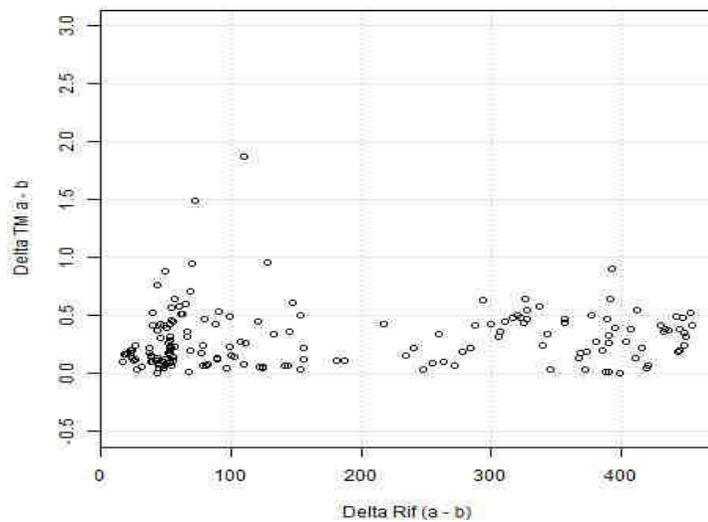
March - Cae1 - soglia su rad rif a 400



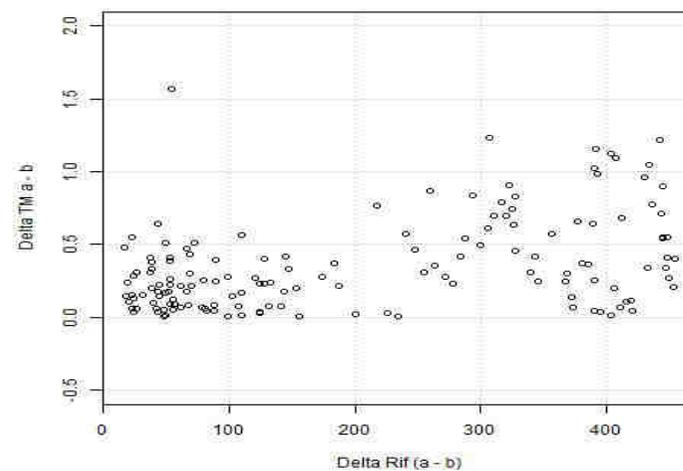
March - Cae2 - soglia su rad rif a 400



March - Barani1 - soglia su rad rif a 400

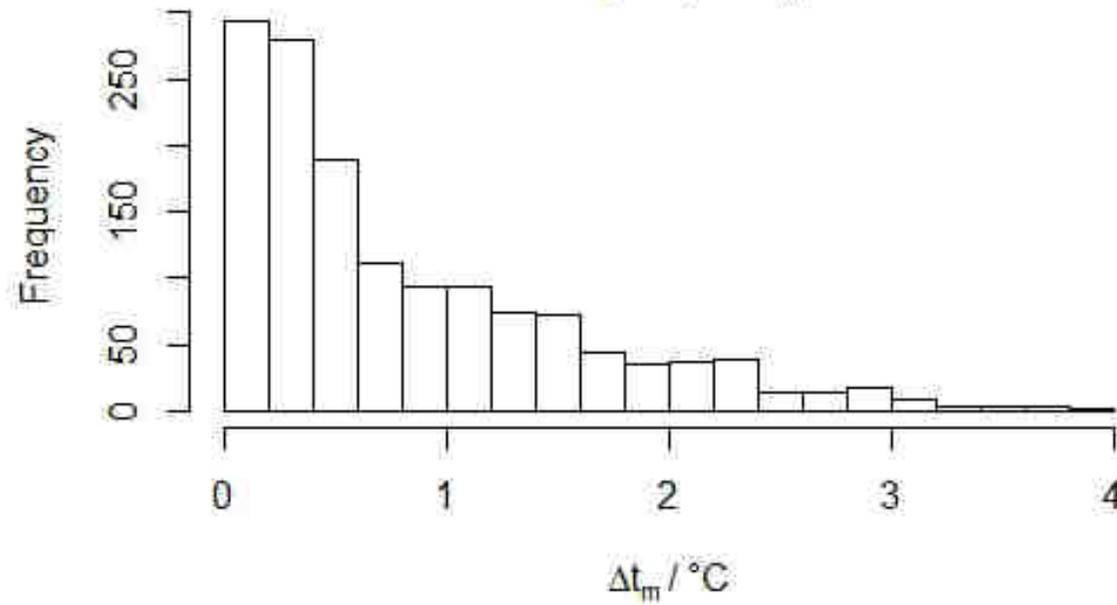


March - Rotronic - soglia su rad rif a 400



- All sensors -

Frequency of Δt_m



The effect of the snow albedo effect on near ground air temperature measurements was investigated both theoretically and experimentally. On site experimental comparison of solar shields by parallel observations of six pairs of instruments exposed and not-exposed to snow albedo showed a maximum temperature difference between couples of identical instruments of 3 °C; the uncertainty of the temperature differences, evaluated in field conditions, is 0.3 °C (k=2).

The contribution of the snow albedo to the uncertainty of near ground air temperature measurements was estimated to be **1.73 °C** (k=2). These results led to two recommendations addressed to the end users and to manufacturers of atmospheric temperature sensors.

Cold rain as uncertainty on near surface air temperature measurements

Influence of rain on thermometers (DTI)

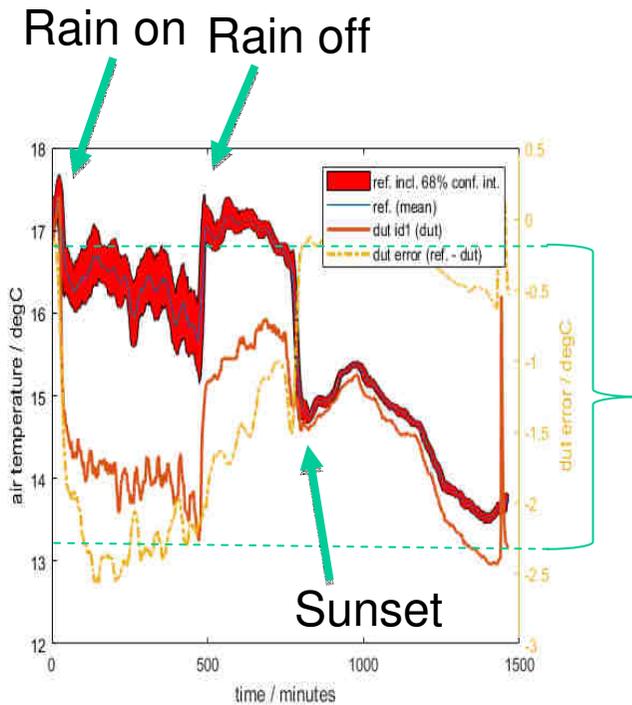
When rain starts, air temperature decreases.

Drops of rain are colder than the air.

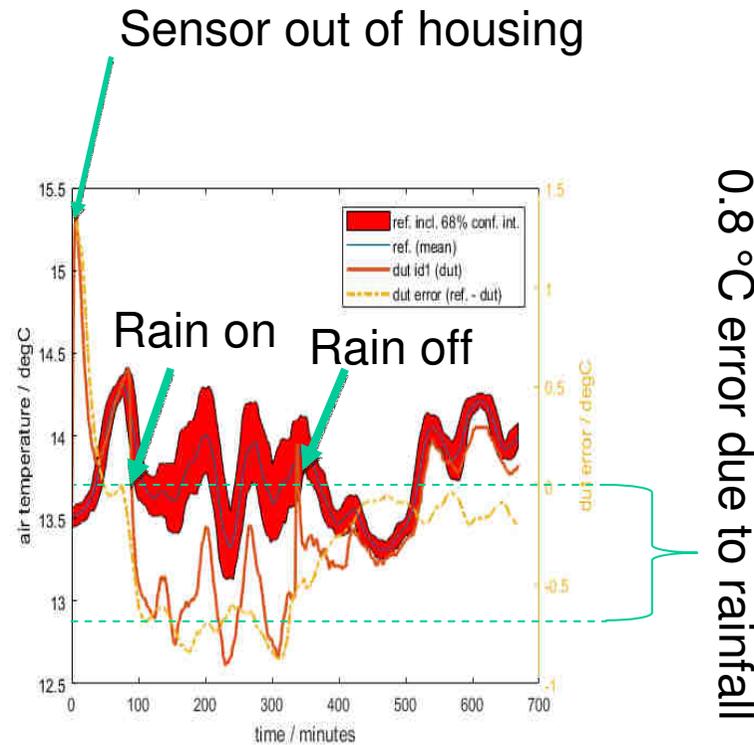
Convection, then conduction cause extra cooling (errors) in temperature measurements.



Weather station without active ventilation



Rain temperature $\approx 6.5 \text{ }^\circ\text{C}$



Rain temperature $\approx 12 \text{ }^\circ\text{C}$

From the preliminary results analysis (May 2017)

- Cooling effect is highly dependent on temperature difference between air and water
- Takes hours for the cooling effect to wear off, after the end of the rainfall
- Latency in the sensors can be significant

GSRN: the GCOS Climate Reference Network

November 2017 starts the GCOS Surface Reference Network

WEATHER CLIMATE WATER
TEMPS CLIMAT EAU

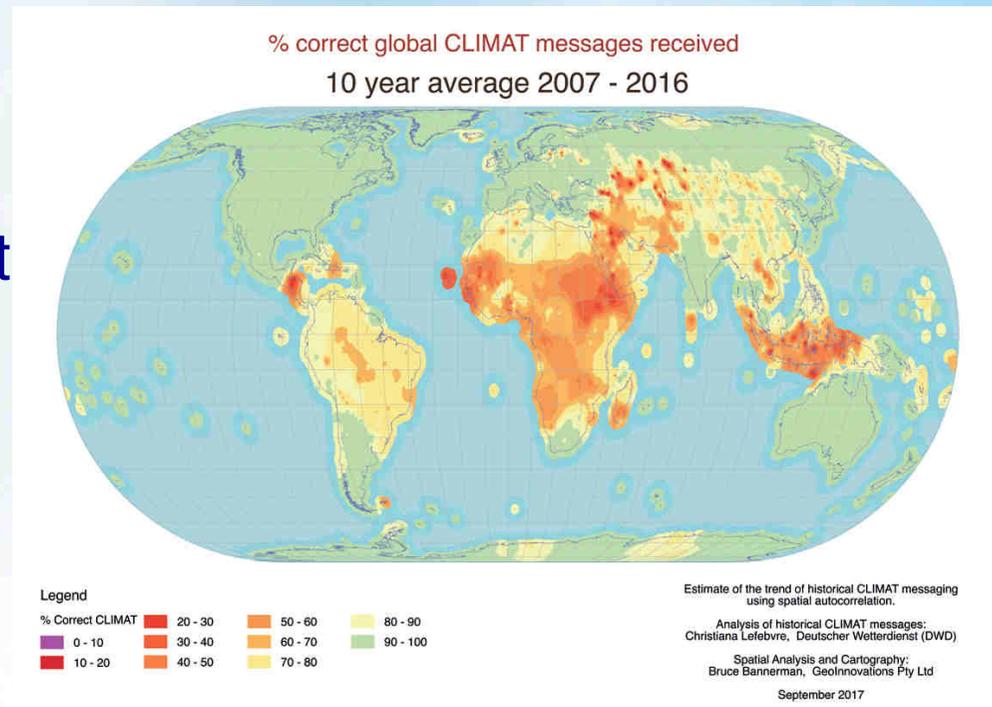
Mission:

Creating global dataset

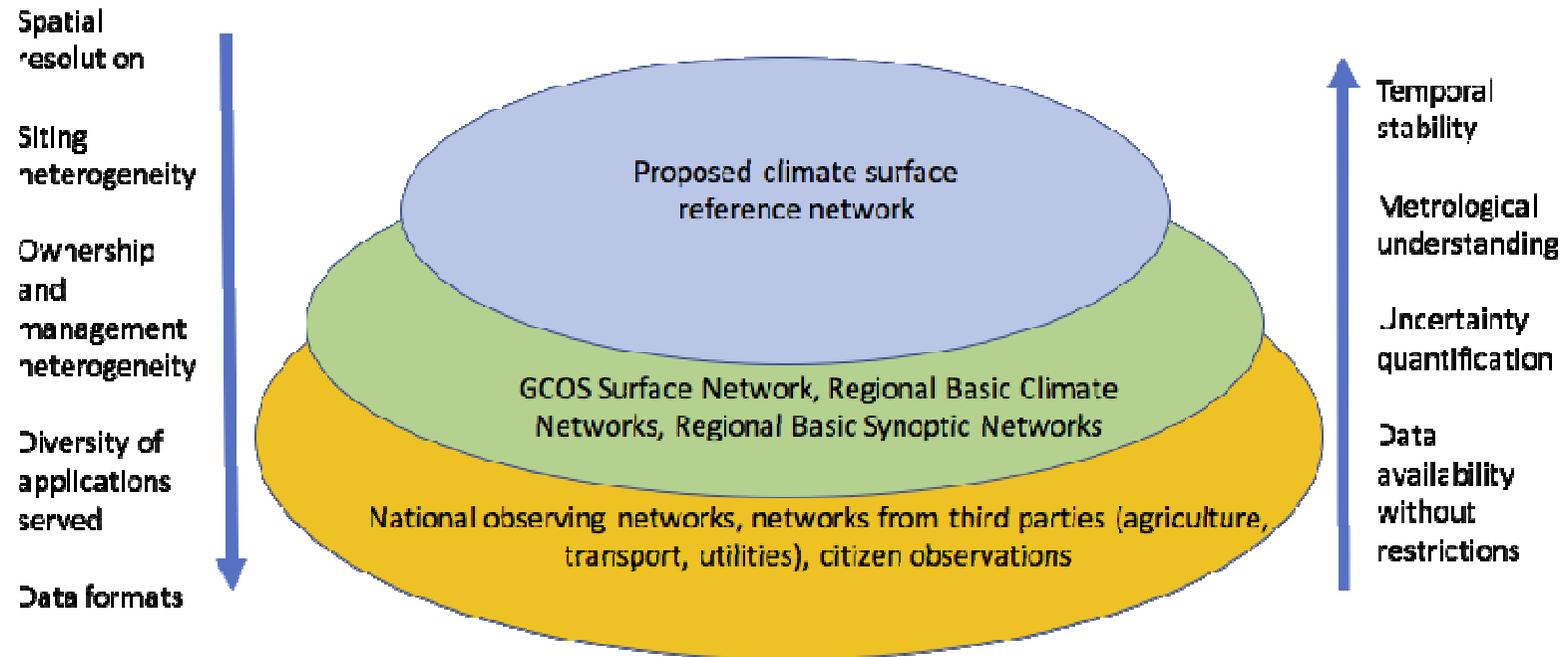


WMO OMM

World Meteorological Organization
Organisation météorologique mondiale



Peer Hechler
Data Management Applications Division
Climate and Water Department



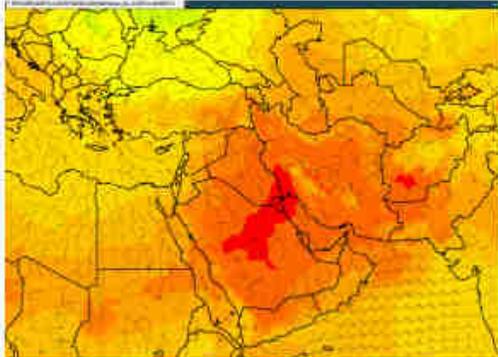
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WMO examines reported record temperature of 54°C in Kuwait

26 Published 26 July 2016

WMO examines reported record temperature of 54°C in Kuwait, Iraq

WMO will set up a committee to examine whether Mirafah, Kuwait, set a new highest temperature record for the Eastern hemisphere and Asia, with a reported temperature of 54.0°C (129.2°F) on 21 July 2016.

Large parts of the Middle East and North Africa were gripped by heatwaves since last week. Temperatures exceeding by a large margin the seasonal averages, and over a sustained period. This affected, in particular, the northern part of countries in the Arabian Gulf and North Africa.

Mirafah reportedly saw a temperature of 54.0°C on 21 July and the city of Basra in Iraq recorded a temperature of 53.9°C (128°F) on Friday 22 July. Southern Morocco also saw temperatures of between 43°C and 47°C.

Governments issued heat-health warnings and took measures to minimise impacts on population. However the refugee population in the Middle East were the most affected, with heat exacerbating their fragile situation and suffering.

WMO is responsible for the official archives of [World Weather and Climate Extremes](#) (temperature, rainfall, wind gust, heaviest hailstone etc).

According to this archive, the hottest temperature ever recorded was in Furnace Creek, Death Valley, California at 56.7°C (134.1°F) on 10 July 1913.

Latest WMO News

- The 63rd National Antarctic Expedition Starts - Reshydromet
1 November 2017
- WMO hosts women's marine leadership workshop
1 November 2017
- WMO and CIMH co-host international training symposium in Barbados
30 October 2017

The Vision for USCRN

Sustain a national climate observing network that in the future, with the highest degree of confidence, can answer the following question:

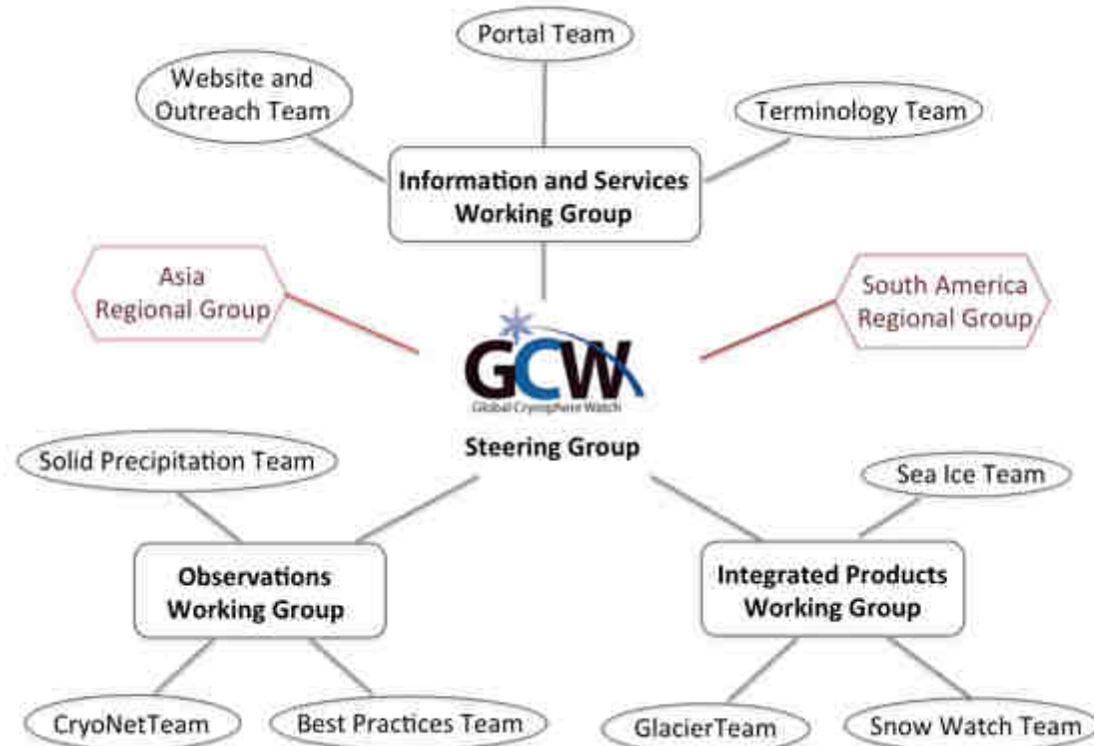
How has the climate changed over the past 50 years?

| Achievements 2013-2017 | Future Scan 2018-2022 | Future Scan 2023-2027 |
|---|--|--|
| Environment | | |
| <p>The RECOMMENDATION T3 (2010) to the CIPM entitled “<i>On climate and meteorological observations measurements</i>” is the basis for establishing long terms collaboration with the scientific community involved in research on climate and environmental monitoring and motivates specific projects and actions from the NMIs being increasingly diffused worldwide.</p> | <ul style="list-style-type: none"> • The relationships with key world and international Institutions such as WMO, GCOS, and IAPWS will be sustained to provide channels for impact in the work of the WG ENV. • CCT recommends NMIs to create Metrology Networks to become reference institutions for the interacting and collaborating with the stakeholders and to preserve, improve and disseminate the experience achieved in thermal metrology for climate and environment. • CCT WG ENV members to continue to contribute as experts in WMO, GCOS task team. | <p>CCT recommends NMIs to include in their vision documents all possible actions within the expertise of the thermal metrology community contributing to improve measurement quality and knowledge on observation and monitoring of the environment and climate</p> |
| <p>The “Metrology for Meteorology and Climate” – MMC Conference series and associated workshops and satellite events</p> <ul style="list-style-type: none"> • were fully participated in and endorsed by CCT WG ENV members • represent world top level events for increasing the collaboration between thermal metrologists and the stakeholder communities. | <ul style="list-style-type: none"> • Data comparability: Include as reliable as possible uncertainty analysis in historical data; study and assess traceability. • Spatial and temporal comparability: Systematic evaluation of environmental and instrumental influences on measurement results; complete knowledge on measured quantity. • Temperature measurements: Improved measurement techniques, calibration procedures and develop, supervise and harmonise guides. • Water content measurements (air and soil): Develop suitable measurement techniques and guides. • Impact: CCT members continue to organize events, meetings, workshops, conferences and training to discuss and plan common activities with the climate and environmental communities. | <ul style="list-style-type: none"> • Air temperature measurements still present open issues in identifying the components of the uncertainties budget and in their evaluation. The evaluation of the uncertainty in atmospheric air temperature measurements, both at ground level and in upper atmosphere, together with a fully documented traceability, is the fundamental condition to achieve data comparability within and among observing networks, in space and time and for the validation of different techniques. • WG Environment to initiate studies and publication on this subject. • In a long-term vision, it is expected that the joint work of metrologists and the user community will improve the knowledge on this key measurement for atmospheric studies and climate monitoring. |
| | <p>The planned creation of a GCOS Surface Reference Network (GSRN) of observing stations on land⁶ will require a continuous support from the thermal metrology community, being temperature and humidity of air and soil key observables.</p> | <ul style="list-style-type: none"> • CCT WG ENV, together with operational meteorologists, climatologists and metrologists, to contribute with studies and activities to GCOS for the definition of the key aspects of GSRN in terms of station features, data characteristics and target uncertainties. • Provide roadmap to address needs of data quality arising from possible new climate evolution scenarios. |

The WMO Global Cryosphere Watch

The World Meteorological Organization's Global Cryosphere Watch (GCW) is an international mechanism for supporting all key cryospheric in-situ and remote sensing observations. To meet the needs of WMO Members and partners in delivering services to users, the media, public, decision and policy makers, **GCW provides authoritative, clear, and useable data, information, and analyses on the past, current and future state of the cryosphere.**

GCW includes observation, monitoring, assessment, product development, prediction, and research[...] to deliver quality-assured global and regional products and services.





Global Cryosphere Watch

World Meteorological Organization

Home About News Cryosphere Now Surface Satellites Activities Reference Data Portal Outreach

Highlights

GCW surface network continues to grow.
 There are now over 140 stations either approved or awaiting approval for inclusion in the GCW surface network. Some are CryoNet stations; some are contributing stations.

Cryosphere in the News

- North American Arctic is falling compared to Russia, Nordics, warns think tank
 3 February 2018, 6:05 am
 rcinet.ca
- Polar bears filmed themselves while hunting seals on sea ice, revealing why they are so at risk from global warming
 3 February 2018, 2:34 am
 feeds.feedburner.com
- The LINK Online, Feb 2, 3, 4 2018
 2 February 2018, 8:40 pm
 rcinet.ca
- Climate threats to polar bears: new study
 2 February 2018, 7:13 pm
 rcinet.ca
- Polar bear videos reveal impact of melting Arctic ice
 2 February 2018, 3:23 pm
 feeds.cbsnews.com

The Cryosphere Now

Sea and Freshwater Ice
 Snow and Solid Precip
 Glaciers & Ice Caps
 Ice Sheets

Greenland Cumulative Melt Days Jan 1 - Jun 25 2017

GCW News

- New eastern Greenland photos in gallery (2018-02-03)
- Sites are now Clusters (2018-02-03)
- GCW Data Protocol for CryoNet is now available (2017-12-04)
- Urumqi Glacier No. 1 in the News (2017-10-28)
- Global Cryosphere Watch (GCW) - Arctic Polar Regional Climate Centres (PRCC) Planning meeting (2017-10-15)

The core of the GCW surface observing network is called

CryoNet.

This network is comprised of *stations* and *sites* which meet certain requirements. The GCW surface network is a component of the WMO Integrated Global Observing System (WIGOS).

CRYONET TEAM

globalcryospherewatch.org/cryonet/site_types.html

Immediate priority: Establish the core standardized GCW surface observation network - CryoNet

- ❖ Network builds on existing cryosphere observing programmes
- ❖ Promotes the addition of standardized cryospheric observations
- ❖ Covers all components of the cryosphere (glaciers, ice shelves, ice sheets, snow, permafrost, sea ice, river/lake ice) through an extensive approach of standardized in situ observations
- ❖ Currently pre-operational with 36 sites and stations globally

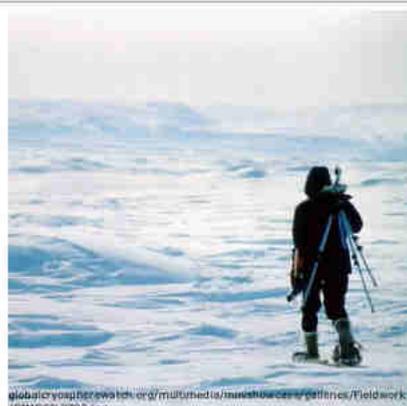
| CryoNet STATIONS |  |
|---|--|
| <ul style="list-style-type: none">○ measure at least one variable of a cryosphere component (e.g. snow, permafrost, sea ice...)<ul style="list-style-type: none">○ have to fulfill CryoNet minimum requirements○ must have ancillary meteorological measurements○ have the target of long-term operation(primary) or long-term operational commitment with 10+ years record (reference) <p><i>Attributes: primary, reference Potential attributes: cal/val, research</i></p> | |
| CryoNet SITES | <ul style="list-style-type: none">○ contain two or more coordinated stations (at least one is a CryoNet station) with varying capabilities that are coordinated as a local cluster○ must have a concept describing the scope of the research approach and the site management <p><i>Attributes: basic, integrated</i></p> |

BEST PRACTICES TEAM

globalcryospherewatch.org/bestpractices/methods.html

- ❖ GCW standards and best practices for cryospheric measurements are currently being compiled
- ❖ Drawing on existing measurement methods
- ❖ Reach scientific consensus
- ❖ An initial inventory of existing documents describing measurement practices is available.

| Cryosphere Element | Existing Documents |
|--------------------------------|--|
| Snow | GEN (2010), Fierz et al. (2009), Armstrong et al. (2009), MSC (2012, 2013), UNESCO, IASH and WMO (1970) |
| Glaciers, ice sheets, ice caps | Kaser et al. (2003), Östrem and Brugmann (1991), Paul et al. (2009), UNESCO and IASH (1970a), UNESCO and IASH (1970b), WGMS (2012), Zemp et al. (2009) |
| Sea ice | JCOMM (2004), MSC (2005), NOAA (2007), WMO (2004), Johnson and Timco (2008) |
| Solid precipitation | Goodison et al. (1998), MSC (2012, 2015), Nitu and Wong (2010), WMO (2012) |
| Permafrost | Smith and Brown (2009), GTN-P (2012) |



C. Hutin





To
Dr. Andrea Merlone
Istituto Nazionale di Ricerca Metrologica
EURAMET Task Group Environment Convenor
And
EURAMET Task Group Environment Members
Strada delle Cacce, 91
10135 TORINO
Italy

Geneva, 10 November 2017

Subject: Expression of interest for the EMPIR Environment call 2019

The World Meteorological Organization's Global Cryosphere Watch (GCW) is an international mechanism for supporting all key cryospheric in-situ and remote sensing observations. To meet the needs of WMO Members and partners in delivering services to users, the media, public, decision and policy makers, GCW provides authoritative, clear, and useable data, information, and analyses on the past, current and future state of the cryosphere. GCW includes observation, monitoring, assessment, product development, prediction, and research. It provides the framework for reliable, comprehensive, sustained observing of the cryosphere through a coordinated and integrated approach on national to global scales to deliver quality-assured global and regional products and services. GCW organizes analyses and assessments of the cryosphere to support science, decision-making and environmental policy.

To meet these objectives, GCW implementation encompasses, among the others, a clear statement on Standardization: Enhance the quality of observational data by improving observing standards and best practices for the measurement of essential cryospheric variables. This includes developing measurement guidelines and best practices; engaging in, and supporting, intercomparison of products, formulating a set of best practices for product intercomparisons.

The GCW surface observation network is comprised of a core component, called CryoNet, and contributing stations that are not part of CryoNet. The GCW network builds on existing cryosphere observing programmes and promotes the addition of standardized cryospheric observations to existing facilities in order to create more robust environmental observatories.

It is under this framework, that GCW has deep interest in implementing metrology and metrological approach. It is therefore of high relevance for GCW that the next EURAMET call on Environment includes support for studying the metrological aspects linked with data quality, including measurement and target uncertainties. In particular, GCW would strongly recommend the inclusion in next metrology joint research activities, networks and projects topics such as:

- measurements in extreme environments, key climate regions and challenging conditions;

In particular, GCW would strongly recommend the inclusion in next metrology joint research activities, networks and projects topics such as:

- measurements in extreme environments, key climate regions and challenging conditions;
- studying reference methods for the Global Cryosphere Watch;

EMPIR Work Programme
Call Scope – Metrology for Environment (2018)
Document: Version: 6.2
Date: 19/06/18



The Call is answering to changes in economy and life style dictated by environmental causes, namely climate change and reduction of the existing resources. The priorities given in the H2020 Work Programme 2018-2020, focus on a climate action in support of the Paris Agreement and on a green economy where the use of natural resources is reduced and managed sustainably.

Climate change remains one of the most challenging problems confronting society. At the Paris climate conference (COP21) in December 2015, 195 countries adopted the first-ever universal, legally binding global climate deal. Governments agreed a long-term goal of keeping the increase in global temperature well below 2°C above pre-industrial levels and to aim to limit the increase to 1.5°C¹. In addition, governments agreed to strengthen societal ability to deal with the impacts of climate change and provide continuous and enhanced international support for adaptation to developing countries. The strongest warming is projected across north-eastern Europe and Scandinavia in winter and southern Europe in summer². In the Arctic the climate change is warming up the region twice as fast as the rest of the world, with global consequences such as sea-level rise, changing weather patterns and more extreme weather events, with socio-economic impact on the European Union.

Air and water quality also continue to be subjects of highest concern having global dimension. They require comprehensive measurement in all ground, surface and marine waters on a routine basis. The Interim Evaluation Report of the European Metrology Research Programme explicitly demands metrological progress in this field describing the European Water Framework Directive as a 'vehicle where the community of NMIs collaborating [...] should be playing a leading role'³.

The EU's ratification of the Paris Agreement in October 2016 triggered its entry into force in less than one year⁴. 20% of the EU budget goes to climate-related expenditure. Climate Water expenditure will exceed 35% of the overall Horizon 2020 budget, at least 40% of the European Fund for Strategic Investments (EFSI) will support projects that contribute to climate action⁵. Thanks to European and international research, our understanding of the causes of climate change has progressed significantly; however we cannot stop here. Today's pressing challenge is to explore and forecast the impacts of climate change and provide effective responses to it⁶.

In line with this European global leading role on climate change, the previous three calls for joint research projects under the EMRP and EMPIR⁷ EURAMET initiatives, in 2010, 2013 and 2015, represented a unique effort worldwide to address metrology in supporting environmental and climate studies. This EMPIR call is planned to continue and progress in this objective and it focuses on metrological research to improve the quality of data, to stimulate technological innovation, and to disseminate traceability to, and make traceable measurements in the field, to address both local and global environmental challenges such as those related to:

- improving the performance and reducing the uncertainty of measurement techniques to meet tighter limit values for pollutants of air and water quality;
- the development and accurate validation of new and emerging technologies, including low cost sensors and satellites.

1 http://ec.europa.eu/research/policies/paris-climate-agreement-2015_en.pdf
2 IPCC AR5 WG2 I, 2.10
3 http://ec.europa.eu/research/policies/interim-evaluation-report-2016_en.pdf
4 <http://ec.europa.eu/commission/press-room/detail/2016/10/18-paris-climate-agreement>
5 <http://ec.europa.eu/commission/press-room/detail/2016/10/18-paris-climate-agreement>
6 http://ec.europa.eu/research/policies/interim-evaluation-report-2016_en.pdf
7 European Metrology Research Programme for research and innovation





- identifying measurands and measurement methods for indoor air quality
- atmospheric science measurements of particulates, aerosols, GHG, ammonia, short lived compounds (such as VOCs) and emerging particulate air quality pollutants (especially black carbon, ~~ultrafine~~ particulate and non-exhaust emissions)
- developing new techniques for automated and remote controlled measurements for water analysis in support of water monitoring in Europe
- improving knowledge and undertakes innovations in radiative transfer modeling
- exploitation of environmental and climate data such as remote sensing data and monitoring equipment (including ground based instrumentation networks), essential for the quality assurance of satellite derived products
- non-satellite monitoring techniques of key parameters to detect local climate evolution with special focus on near surface thermal quantities, striving for traceable, reference quality, physical measurement series to robustly check the 2°C goal
- **the creation of the global surface science reference network**
- **measurements in extreme environments, key climate regions and challenging conditions,**
- **studying, evaluating and comparing reference methods for the Global Cryosphere Watch** (temperature, pH, pCO₂, salinity and fluorescence-based chlorophyll-a).

Proposals addressing one or more of these challenges will be preferred which aim at the development of a joint, sustainable, and coordinated European landscape of metrology capabilities, supported by the involved communities of national metrological organizations, international bodies such as WMO and GCOS, and the climate research community. One of the purposes set in Article 2(c) of the WMO Convention, is 'to promote the standardization of meteorological and related observations and to ensure the uniform publication of observations and statistics'. GCOS has published its new implementation plan in 2015, which gives recommendations and suggest actions on achieving a number of goals supporting (inter alia) global and local climate observations. 'Climate observations are essential for understanding the complexities of the global climate system [...]. Observations provide critical benchmarks for testing and further developing our predictive capability through models'. This call addresses especially such large-scale, long-term approaches which are beyond the capabilities of single NMIs and DAUs.

This Targeted Programme will enable collaborative research for large and transnational monitoring systems. EURAMET wishes to put a focus on reliable climate data and especially welcomes proposals enabling the establishment of long-term European NMIs networks coordinating the measurement infrastructures in this area and links to present and future potential global networks, in collaboration with user communities. To enhance the impact of the R&D work, the involvement of the user community such as industry, academia, meteorological organizations and agencies, climate research, standardization and regulatory bodies, is strongly recommended.

This Targeted Programme is related to the previous calls on metrology for environment in the EMRP and EMPIR and will allow projects that further the aims of existing projects. It keeps the EURAMET Strategic Agenda as reference document with the aim to complete the subjects there identified and fulfil the objective.

The impact criterion of the proposal selection process will reflect this objective.

8 Global Climate Observing System. The GCOS is co-sponsored by the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the United Nations Environment Programme (UNEP), and the International Council for Science (ICSU).
9 World Meteorological Organization

EMPIR Call 2018
Call Scope – MFE
- 2 -
www.empr.eu

Arctic Metrology Workshops series



1st Torino April 2015
2nd Oslo May 2016
3rd Ny-Ålesund 2017



•Break out session @ Arctic Circle 2015



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16 - 18 OCTOBER**

2015 PROGRAM

ABOUT BOARD PARTNERS SECRETARIAT PRESS & MEDIA 2014 IMAGES VIDEO



HASKÓLINN Í REYKJAVÍK
REYKJAVÍK UNIVERSITY

THE FUTURE OF ENERGY SECURITY IN THE ARCTIC

The Iceland School of Energy will organize a session on Thursday, October 15th, about the future of Arctic energy, with considerations of environmental and human security. The session will be organized in cooperation with the Harvard Kennedy School of Government and the Fletcher School of Law and Diplomacy at Tufts University.



THE FOREIGN MINISTER OF CHINA

The Opening Session of the 2015 Arctic Circle Assembly will include an address by the Foreign Minister of the People's Republic China, Wang Yi.



EURAMET

METROLOGY FOR ENVIRONMENT IN THE ARCTIC

High-accuracy measurements are needed to understand the evolution of the Arctic environment in its many extremes. EURAMET, the European Association of National Metrology Institutes, is hosting a breakout session promoting common activities between metrology and Arctic scientific research to improve data quality.

*Esteemed participants in the
Arctic Metrology Workshop,*

*I am particularly pleased to address
my greetings to you from Oslo and my
best wishes in your work.*

*I believe metrology and EURAMET are
bound for keeping a key role in this
crucial region.*



Giorgio Novello, Italian
Ambassador in Norway
and Iceland

MMC ^{Spain} 2016



METROLOGY FOR METEOROLOGY AND CLIMATE

26-30 September 2016
Spain (Madrid)

&



CIMO-TECO

ENVRIPlus Meeting
Soil Moisture Workshop
MeteoMet2 plenary meeting



BIPM



TC-T
Thermometry
EURAMET Technical Committee

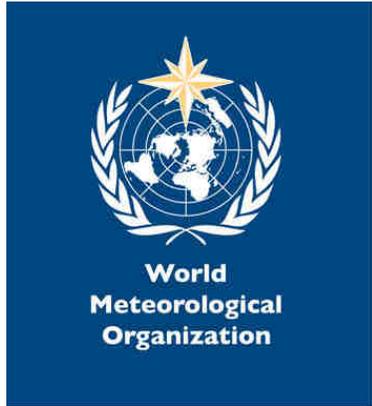
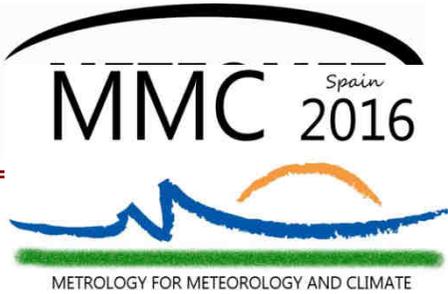


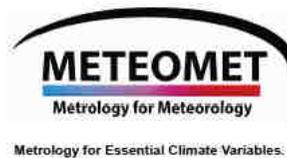
TC12

GRUAN



APMP





International Workshop and roundtable on
Metrology for High Mountains Climate Observational Issues



15 February 2017

Venue:
Società Meteorologica Italiana
Via Real Collegio, 30, Moncalieri (Torino), Italy



Wokshop outcomes

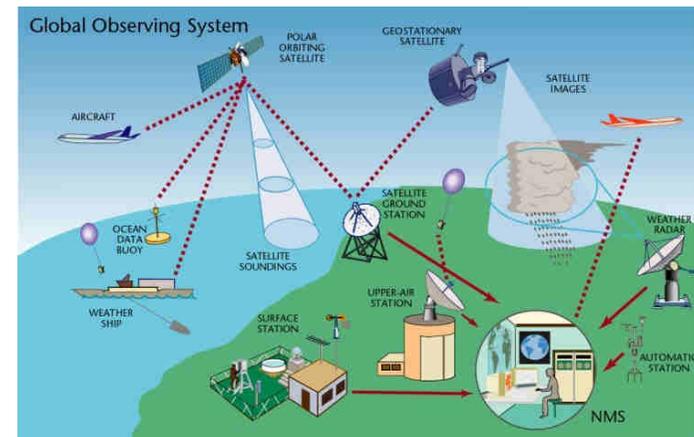
- More comparability required (in time, among different stations and sensors)
 - Need to evaluate measurement uncertainty and a common evaluation process
 - Dedicated calibration procedures
 - Reduce variety of principles, sensors, instruments, systems, dataloggers,
 - Standard methods to be defined (in line with GCW recommendation)
 - Specific requirements for reference sites
-
- Opening the discussion for planning a roadmap is strongly suggested

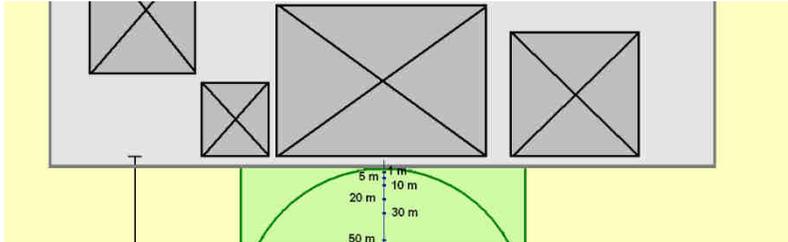
Thank you

Calibrations and Uncertainties evaluations to establish complete traceability

Traceability is the key conditions for comparability

- Comparability on climate-change scales
- Comparability to fundamental physical models
- Comparability across generations
- Comparability across borders & organizations
- Comparability across instrument/measurement types





- Three identical experiments in three nations (Italy, Spain, Czech R.)
- Only variable is the nature of the obstacle

obstacle

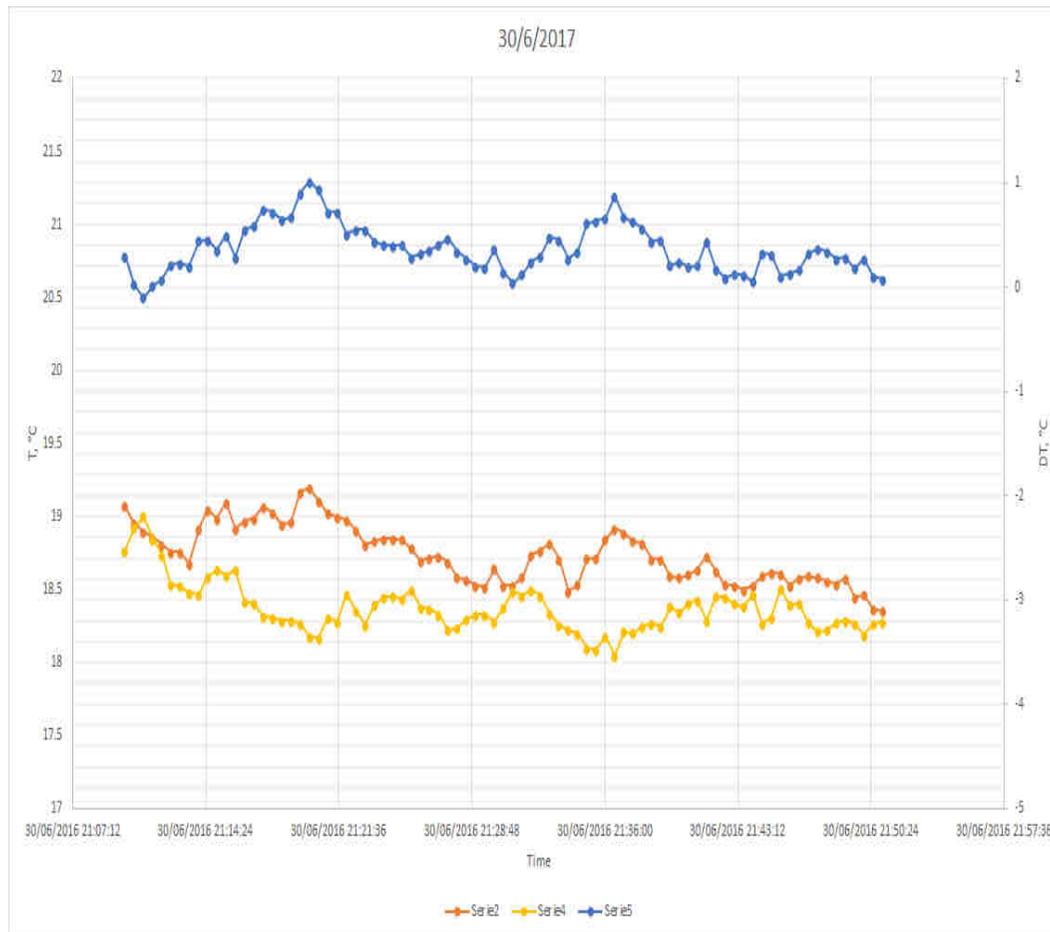
| Distance (m) | PT 100 thermometers with protection shields | Hygrometers | Anemometers | Solar radiation meters |
|--------------|---|-------------|-------------|------------------------|
| 01 | 2 | | | |
| 5 | 1 | | | |
| 10 | 1 | 1 | | |
| 20 | 1 | | | |
| 30 | 1 | 1 | 1 | 1 |
| 50 | 1 | | | |
| 100 | 1 | | | |





Building - CEM

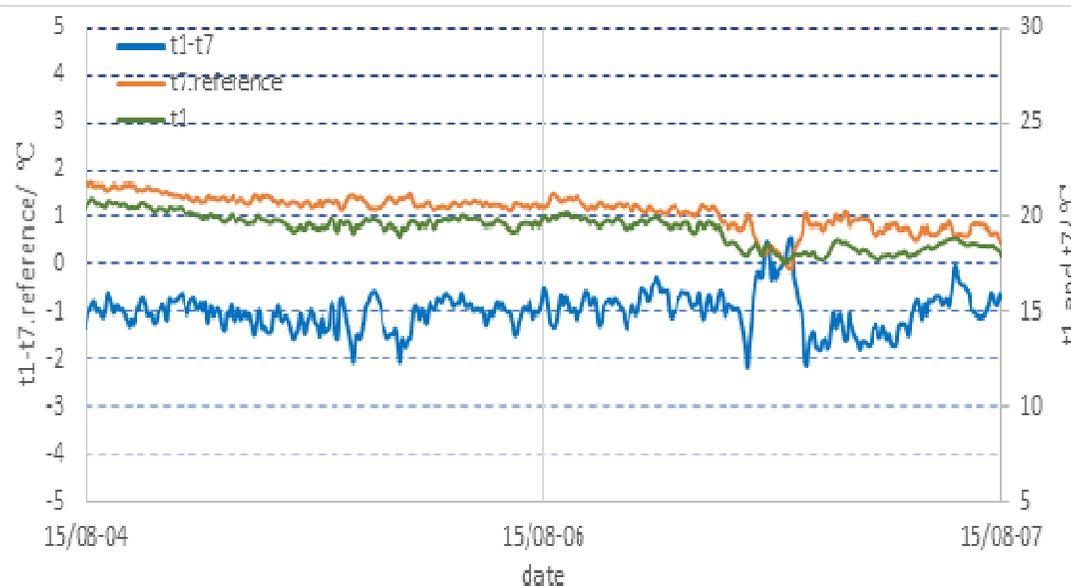
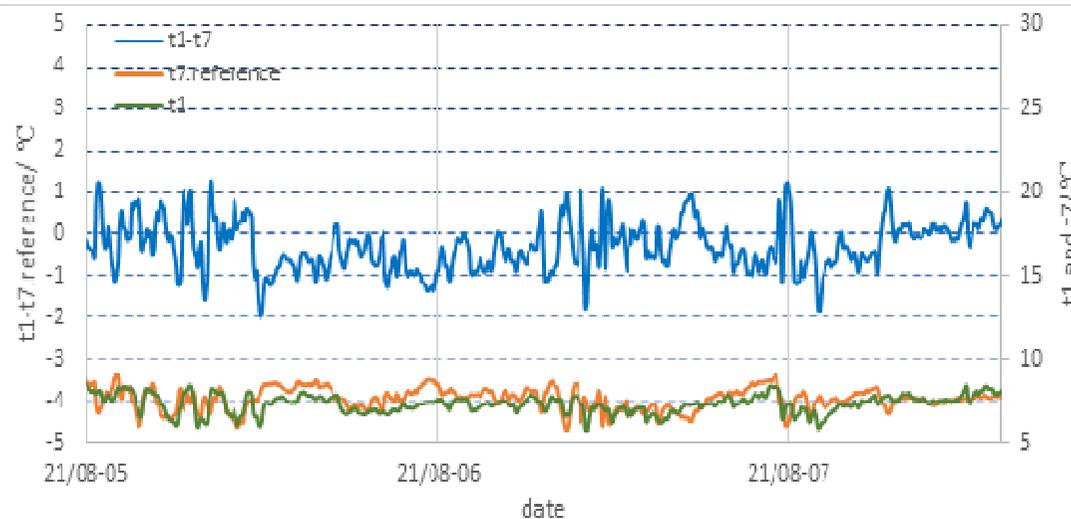




A 0.5-1 °C sustained event. It lasted more than 1 hour. Sensor #1 (orange) and #7 (yellow) show no fast transients.

Event attributable to road effect.

Influence of the ambient temperature on building effect at **night**, without sun radiation



Summer:
Building effect with lack of sun radiation (at night) does not depend on the reference temperature:

Building effect = -1 °C

Atmospheric air temperature measurements:

**can we evaluate a complete uncertainty
budget?**

A thermometer measures the temperature of the air.



A thermometer measures the **temperature** of the air.



A thermometer measures the **temperature** of the **air**.



A (contact) thermometer gives an indication of its heat equilibrium at **that** time in **that** place under **those** conditions.

- **Convection heat exchange**
 - Gas (wind) speed
 - Turbulent, laminar or mixed flow
 - Heat transfer coefficient
 - Convection surface area
 - Temperature gradients
- **Conduction heat exchange**
 - Coefficient of conductivity
 - Thickness of the conduction/insulation layers
 - Temperature gradients
- **Radiation heat exchange**
 - Emissivity coefficients
 - Reflectivity coefficients
 - Diathermy
 - Sub-surface conductivity (surface temperature)
 - Temperature difference
- **Phase change and heat sources**
 - Condensation/evaporation
 - Sublimation/melting
 - Heat sources in the thermometer body
- **Transient heat transfer**
 - Specific heat capacity of the thermometer
 - Mass of the thermometer
 - Initial temperature of the thermometer
 - Gas temperature dynamics (lag)

- Probe is not adiabatic
 - Radiation exchange with surrounding
 - Convection between the probe and air
 - Conduction along probe stem
- Probe has imperfect geometry:
 - Partial stagnation
 - Stagnation different in laminar, turbulent or developing flow
- Flow is compressible at stagnation locations even at mainstream velocities less than $1/3$ Mach
- Probe has finite mass – therefore time lag
- Probe has relatively large heat capacity vs. air
- Probe faces enclosures/surroundings with temperature:
 - different from gas
 - different from probe
- Probe indicates mean temperature (gas, probe body), not gas temperature.
- Difference of self-heating in air to that at calibration should be considered
- Real gas does not have one single total temperature

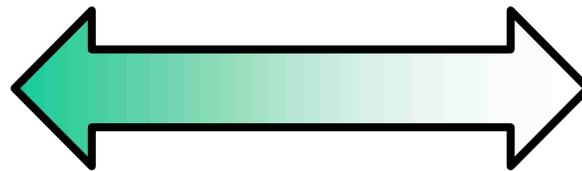
A (contact) thermometer is calibrated in (as close as possible) adiabatic conditions.



A (contact) thermometer is calibrated in (as close as possible) **adiabatic** conditions.



But then a thermometer for atmospheric air temperature measurement is used in **non-adiabatic** conditions

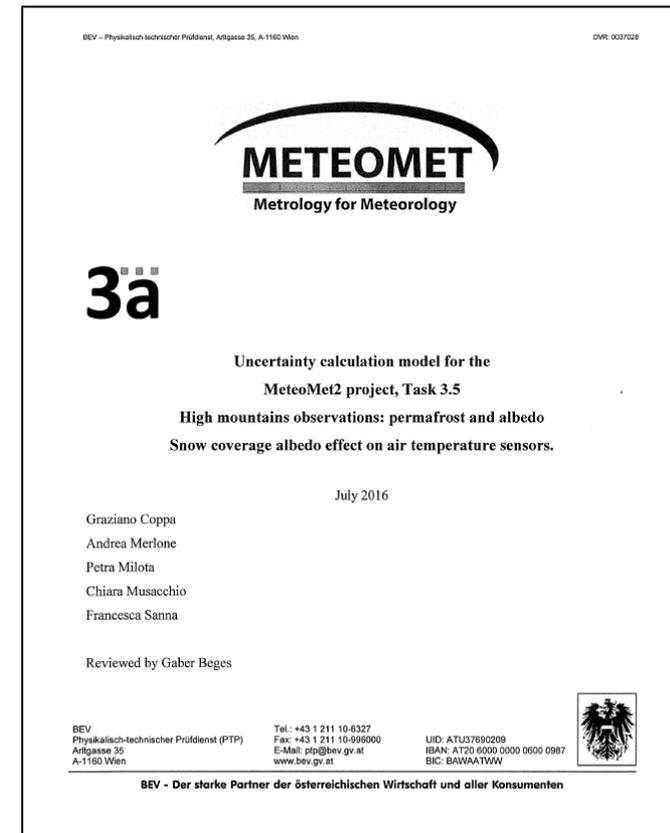


Traceability

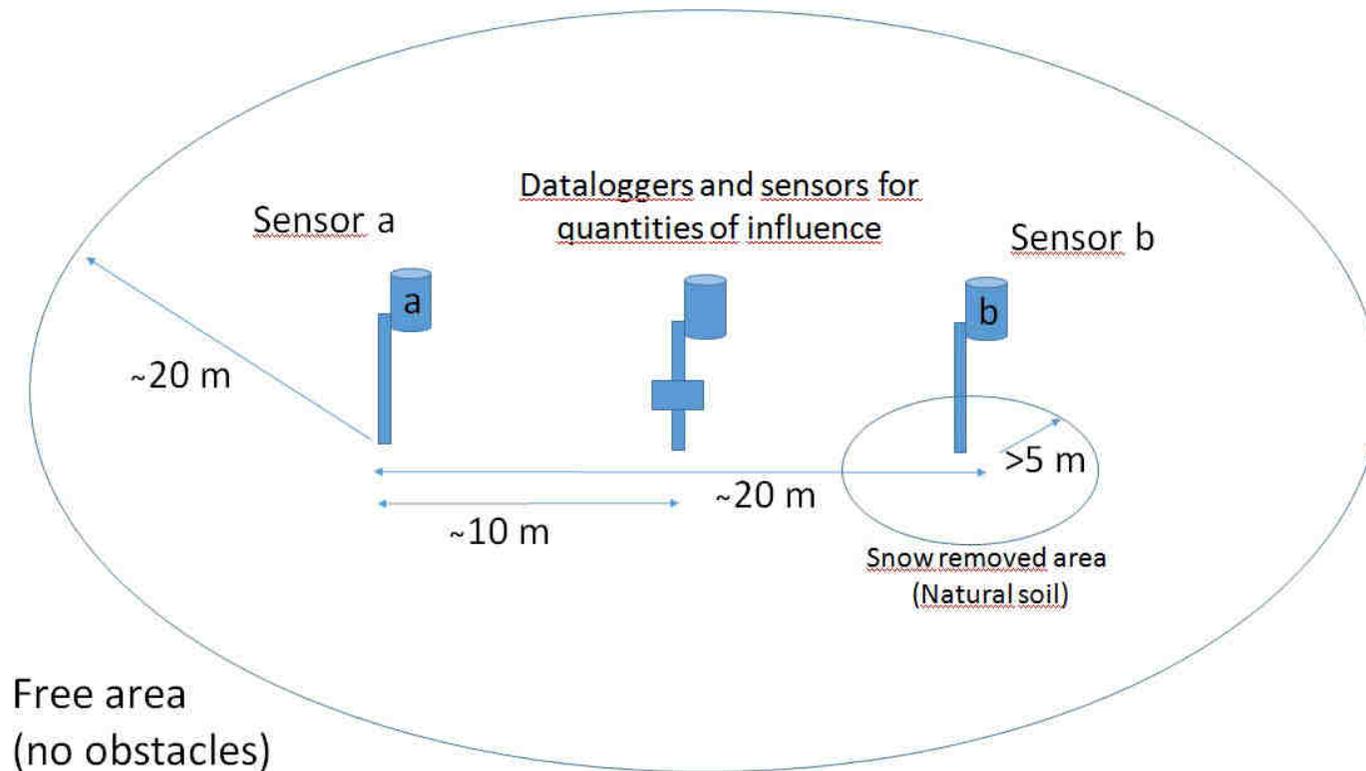
1) Preparation of the experiment protocol and method for the evaluation of all uncertainty components.

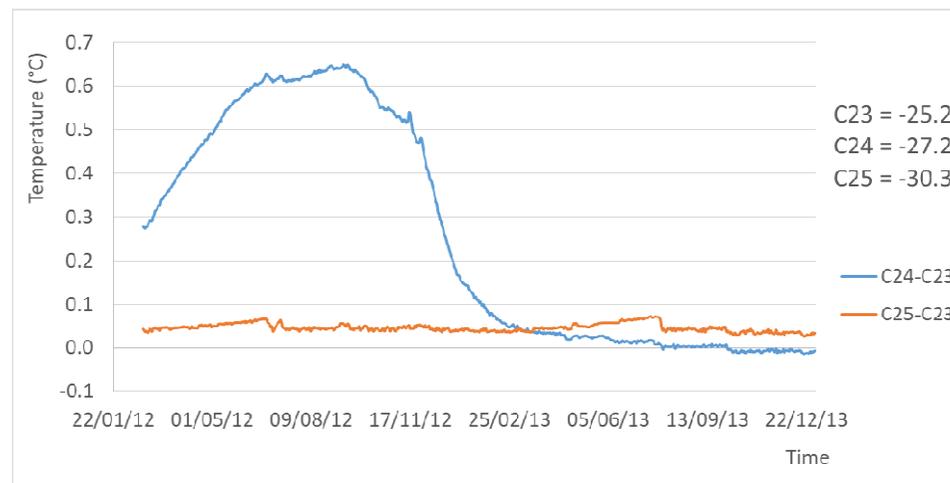
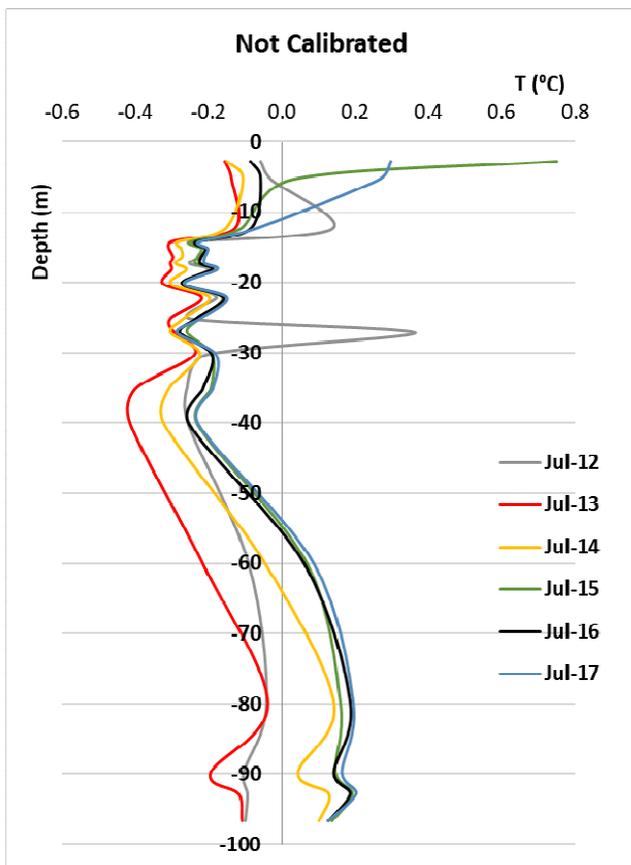
Prescriptions are given on

- 1) how to design the experimental setup
- 2) definition of site requirements
- 3) measuring and evaluating the quantities of influence;
- 4) making relative measurements to get rid of most of the influencing quantities
- 5) characterising the sensors in laboratory and in field
- 6) theoretical assumptions and practical applications



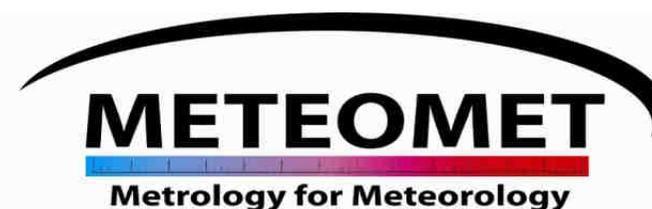
1) Preparation of the experiment protocol and method for the evaluation of all uncertainty components





METROLOGIA PER LE OSSERVAZIONI AMBIENTALI. VERSO NUOVI STANDARD E METODI

Andrea Merlone



BIPM – CCT WG Environment chair
EURAMET TG Environment chair
IMEKO TC 12 Scientific Secretary
MeteoMet coordinator



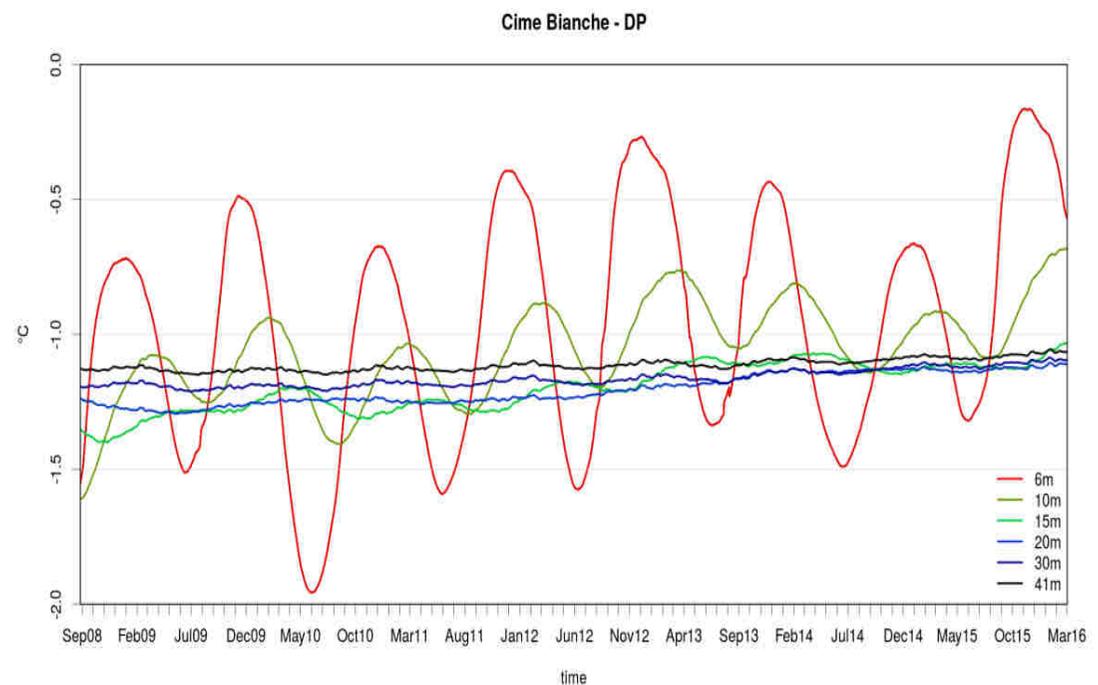


Accuracy

Accurate Measurements

Are needed to assess
and reduce time
necessary to capture
trends

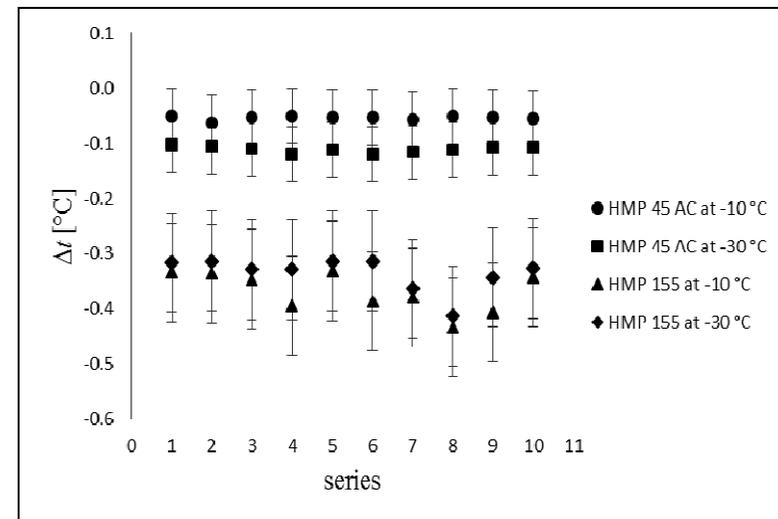
Closeness of the agreement
between the result of a
measurement and a true value of
the measurand



Uncertainty

...dispersion of the values that could reasonably be attributed to the measurand

The uncertainty is evaluated by completing the uncertainty budget



Type A uncertainties: Statistical
Type B: all the rest

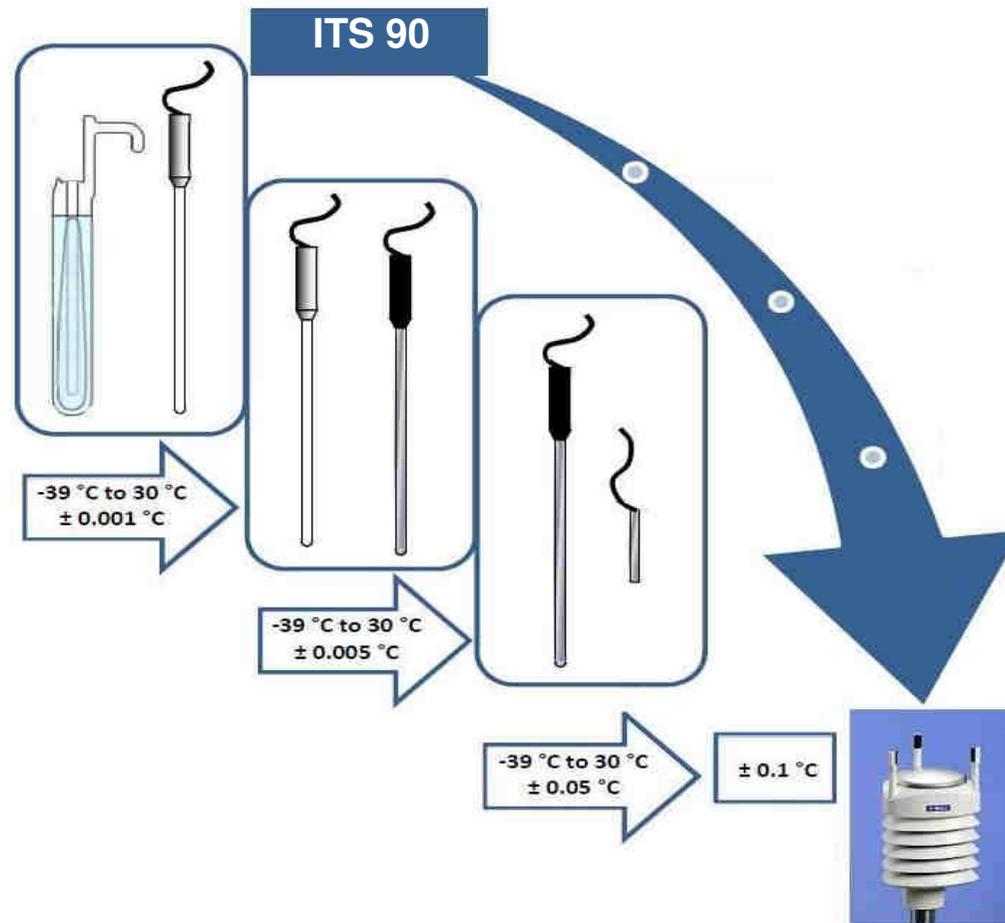
| x_i | $u(x_i)$ [°C] | |
|--|----------------------|----------------------|
| | HMP 155 | HMP 45 AC |
| Components derived from the reference thermometer | $5.12 \cdot 10^{-3}$ | $5.02 \cdot 10^{-3}$ |
| Components derived from measurement system | $1.27 \cdot 10^{-2}$ | $1.27 \cdot 10^{-2}$ |
| Components derived from meteorological thermometer | repeatability | $3.47 \cdot 10^{-2}$ |
| | resolution | $4.04 \cdot 10^{-3}$ |
| | reproducibility | $1.40 \cdot 10^{-2}$ |
| | hysteresis | $2.00 \cdot 10^{-2}$ |
| $u(x) = (\sum u^2(x_i))^{1/2}$ | | $4.45 \cdot 10^{-2}$ |
| $U(x) = 2 \cdot u(x)$ | | 0.090 °C |
| | | 0.050 °C |

**The calibration uncertainty
is NOT
the measurement uncertainty.**

Traceability (Riferibilità metrologica)

“property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty”.

*property of a measurement result whereby the result is related to a reference through a documented unbroken chain of calibrations, and the measurement uncertainty is composed of each of the calibration uncertainties **and contributions due to the measurement conditions.***





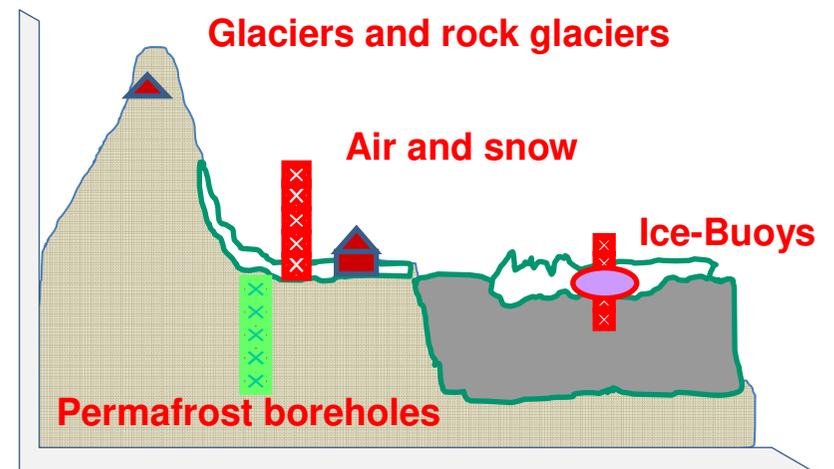
ITS 90



TRACEABILITY

Traceability is required
to reach full comparability

- Comparability on climate-change scales
- Comparability to fundamental physical models
- Comparability across generations
- Comparability across borders & organizations
- Comparability across methodologies



Did you know?...

New SI in 2018. Based on fundamental constants.

Last values submission to CODATA: **01 July 2017**

Adoption of new SI: **CGPM 2018**

Practical change in the defined standards: **20 May 2020**

The (new) SI will be the system of units in which:

- the ground state hyperfine splitting frequency of the caesium 133 atom (^{133}Cs)_{hfs} is exactly 9 192 631 770 hertz,
- the speed of light in vacuum c is exactly 299 792 458 metre per second,
- the Planck constant h is exactly $6.626\ 06\text{X} \times 10^{-34}$ joule second,
- the elementary charge e is exactly $1.602\ 17\text{X} \times 10^{-19}$ coulomb,
- the Boltzmann constant k_B is exactly $1.380\ 6\text{X} \times 10^{-23}$ joule per kelvin,
- the Avogadro constant N_A is exactly $6.022\ 14\text{X} \times 10^{23}$ reciprocal mole,
- the luminous efficacy K_{cd} of monochromatic radiation of frequency 540×10^{12} Hz is exactly 683 lumen per watt,

New definition of the kelvin.

The kelvin, symbol K, is the SI unit of thermodynamic temperature; its magnitude is set by fixing the numerical value of the Boltzmann constant to be equal to exactly $1.380\,65X \times 10^{-23}$ when it is expressed in the SI base unit $\text{s}^{-2} \text{m}^2 \text{kg K}^{-1}$, which is equal to J K^{-1} .

Thus one has the exact relation $k = 1.380\,65X \times 10^{-23} \text{ J/K}$. The effect of this definition is that the kelvin is equal to the change of thermodynamic temperature T that results in a change of thermal energy kT by $1.380\,65X \times 10^{-23} \text{ J}$.

But no worries...

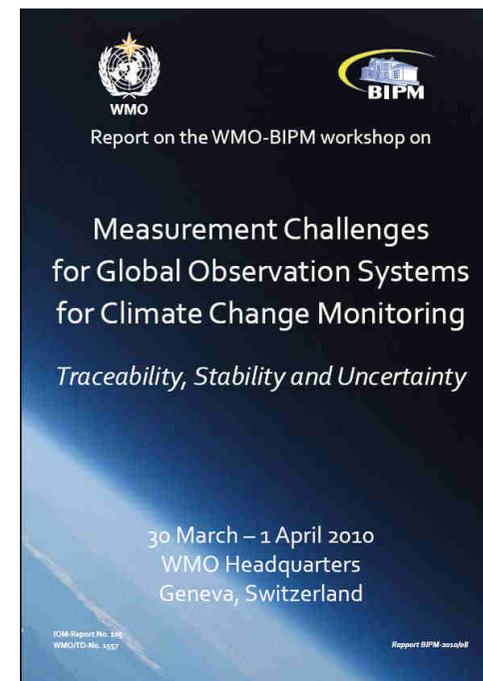
ITS-90 will remain for years (decades...).

And temperature will still be measured and expressed in kelvin (K) or degrees Celsius (°C).

And the conversion from kelvin to degrees Celsius does not introduce any uncertainty.



Michel Jarraud, Secretary General of the WMO, signed the Arrangement on behalf of the WMO. The signing ceremony took place on 1 April 2010



Left to right: Len Barrie (WMO), Andrew Wallard (Director BIPM), Michel Jarraud (Secretary General WMO), Ernst Göbel (President CIPM), Wenjie Zhang (WMO)

2010 May 4-7.

XXV Comité Consultatif de Thermométrie (CCT) meets and prepares a significant reccomendations for the CIPM.



2014 CCT launches WG ENV - A. Merlone Chair

25th Meeting of the
CCT • 51

RECOMMENDATION T 3 (2010)
On climate and meteorological observations measurements

The Consultative Committee for Thermometry (CCT),

considering that

- global average temperature records are essential in understanding how the climate is changing;
- the consequences of these changes have deep impacts on different aspects of social, political and economic life;
- the need exists to improve the quality of data collection by assuring worldwide traceability in measurements involved in climate studies and meteorological observations, as expressed by climate-data users and during the recent WMO-BIPM joint workshop on "Measurement Challenges for Global Observation Systems for Climate Change Monitoring: Traceability, Stability and Uncertainty" (Geneva March 2010);

- the signing of the MRA by WMO will lead to closer liaison and cooperation with the thermal metrology community;

recommends

- to encourage NMIs and the scientific community, especially temperature metrologists, to be prepared to face new perspectives, needs, projects and activities related to the traceability, quality assurance, calibration procedures and definitions for those quantities involved in the climate studies and meteorological observations;
quality assurance needs of the climate change and monitoring communities.
- to support a strong cooperation between NMIs and Meteorological Institutions at local, national and international levels;
- to encourage NMIs to work with the relevant meteorological networks to support a monitoring framework for traceable climate data over long temporal terms and wide spatial scales based on best practice metrology;



EURAMET is the European Association of National Institutes of Metrology.

Manages the European research programs in metrology, under the article 185.



EURAMET Task Group
Environment. Established
2014 to contribute to the
**Strategic Research
Agenda**

**Convener:
Andrea Merlone**



Environment impact report

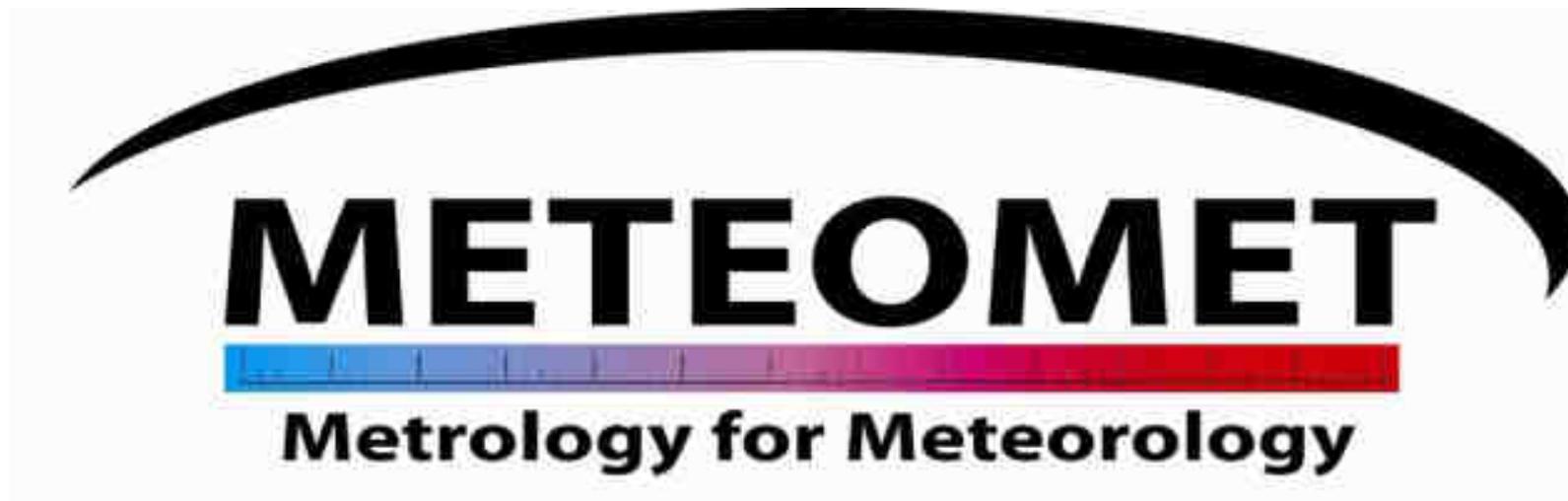
A summary of the outputs and impact of the first EMRP joint research projects in Environment.

The aim of this theme is to improve data quality for environmental policy making, underpin environmental research activities and stimulate technological innovation. The research is focused at both the local environmental level for air, water and soil quality and at the global level for challenges relating to climate change.

EURAMET e.V. - the European Association of National Metrology Institutes

2011 October 1.

MeteoMet Joint Research Project official start date!



METEOMET

2011 -> 2017

Andrea
Merlone

METEOMET

Metrology for Meteorology

Meteomet is a EURAMET joint
research project



11 M€ Budget
300 Deliverables
960 Man months
(80 years!)

**MeteoMet is the
larger EURAMET consortium**

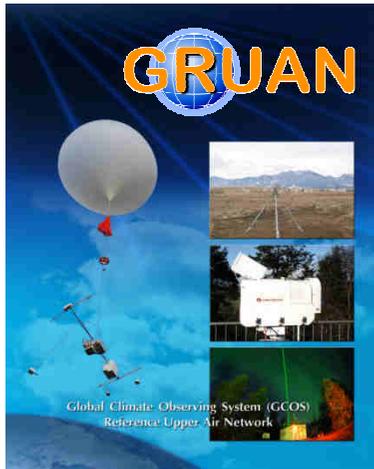
24 National Institutes of Metrology
12 Universities
13 Research centers
9 Instrument Companies
12 Meteo agencies

Andrea Merlone



MeteoMet is the only project addressing metrology to

Radiosondes
Measurements
and GRUAN



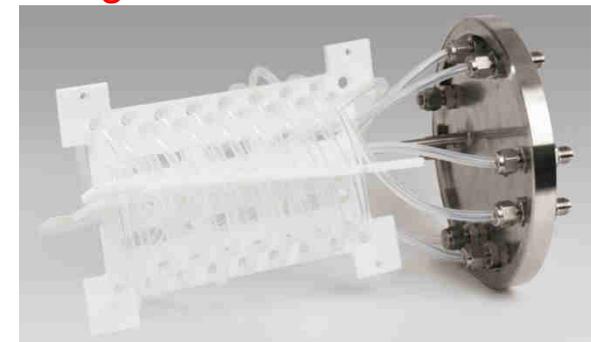
Temperature and
pressure effects on
new generations of
salinometers



Airborne humidity sensors



Water vapour
enhancement factor
And portable
generators



Thermodynamic
calibrations for
environment



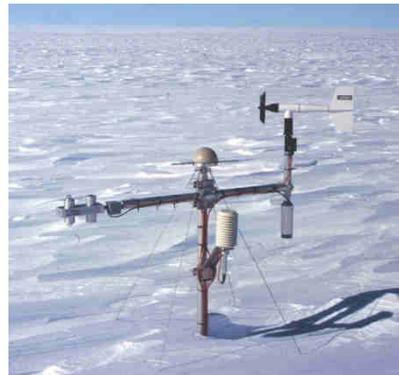


Deep sea thermometers:
•temperature-resistance
linearisation model
•Pressure dependence

Field siting
Classification and
uncertainty



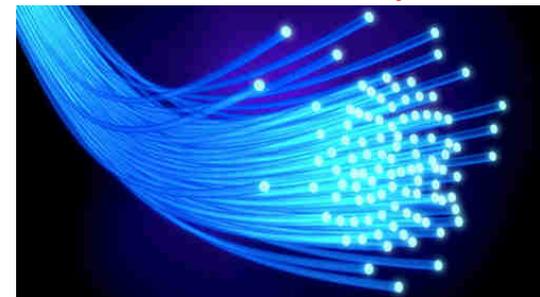
Permafrost measurements
and snow albedo effect



Temperature sensors
dynamics and non contact
thermometry



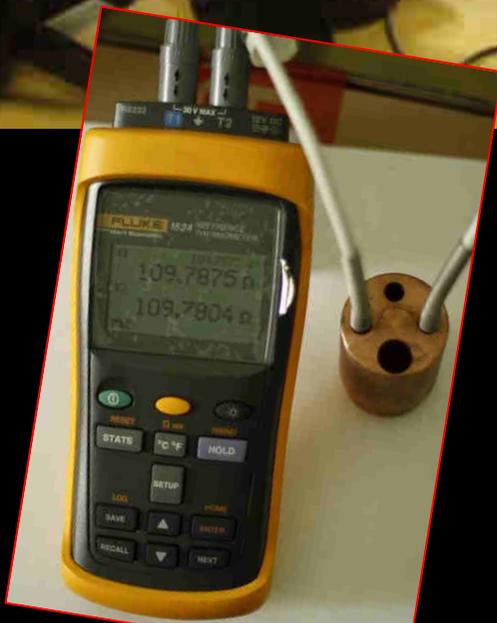
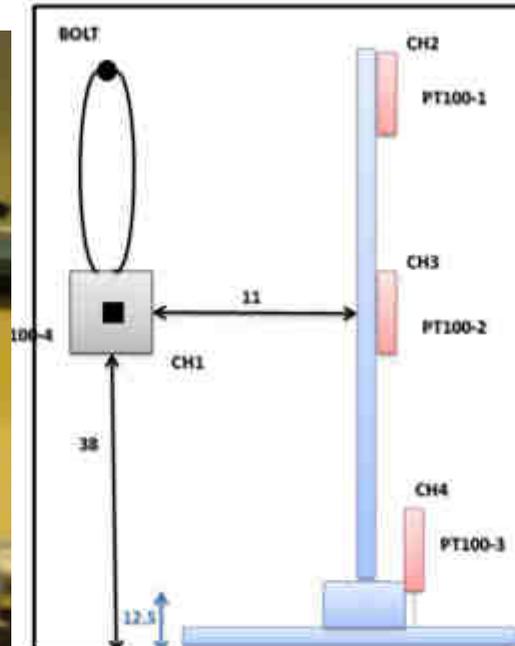
Sea temperature
measurements by
means of fiber optics



Metrology for the Cryosphere



July 2013 characterisation tests and training of Pyramid operators



❖ August 2013 EDIE2 goes to Kathmandu first...







Assembling the calibration chamber
and auxiliary equipment in the Everest Pyramid.



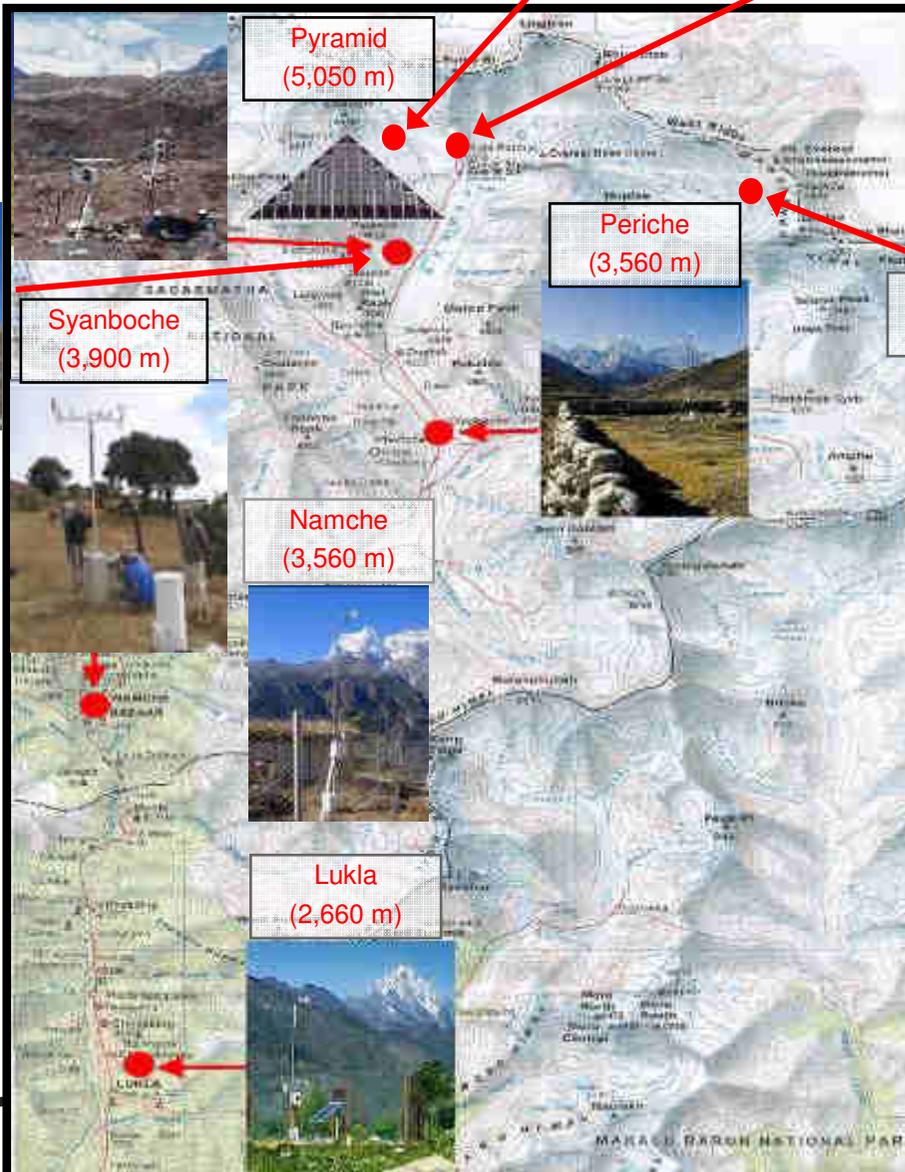
Changri Nup
(5,750 m)



Kala Patthar
(5,550 m)



NCOP-P
(5,079 m)



Pyramid
(5,050 m)

Periche
(3,560 m)

South Col
(7,986 m)

Syanboche
(3,900 m)

Namche
(3,560 m)

Lukla
(2,660 m)



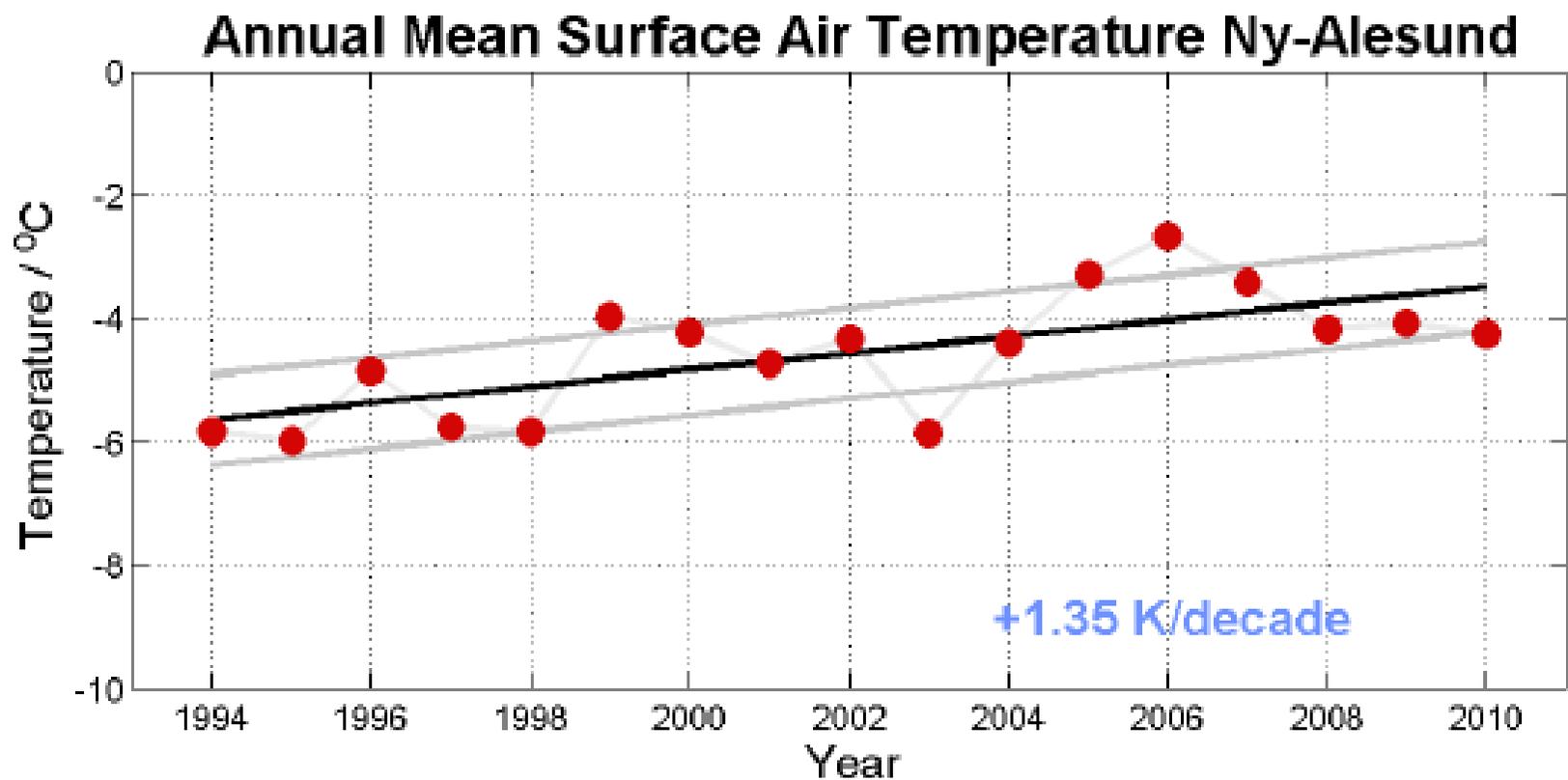
MeteoMet and SHARE project for the data traceability on the Kumbu valley and Everest Nepal side



Arctic Metrology

Mission “Arctic Metrology” 2014

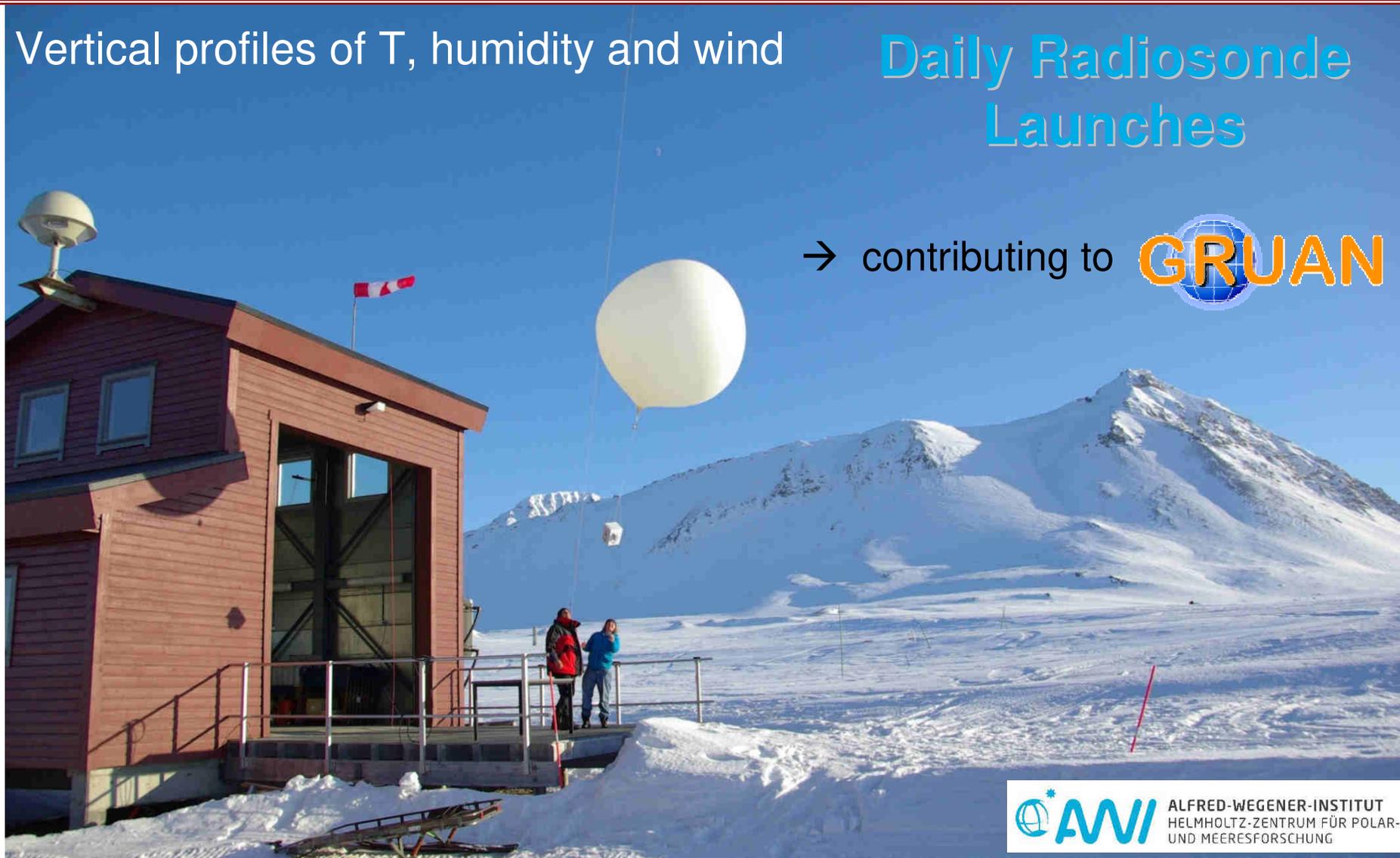




Vertical profiles of T, humidity and wind

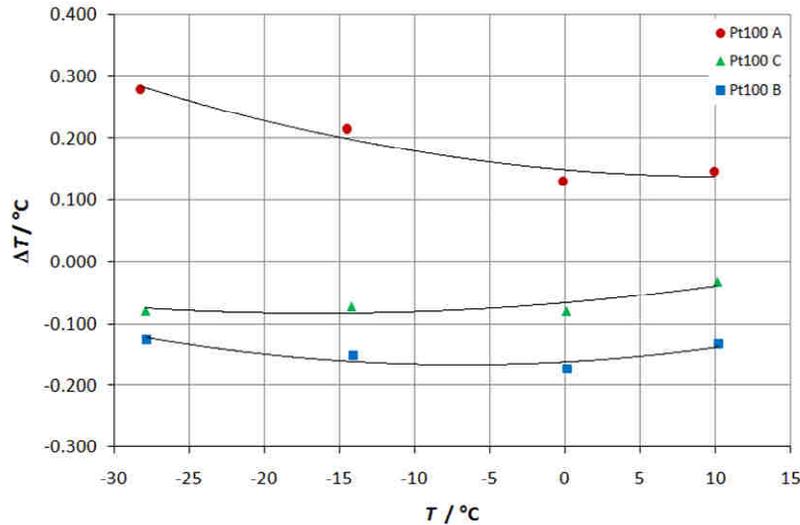
Daily Radiosonde Launches

→ contributing to **GRUAN**



INRiM & AWI People

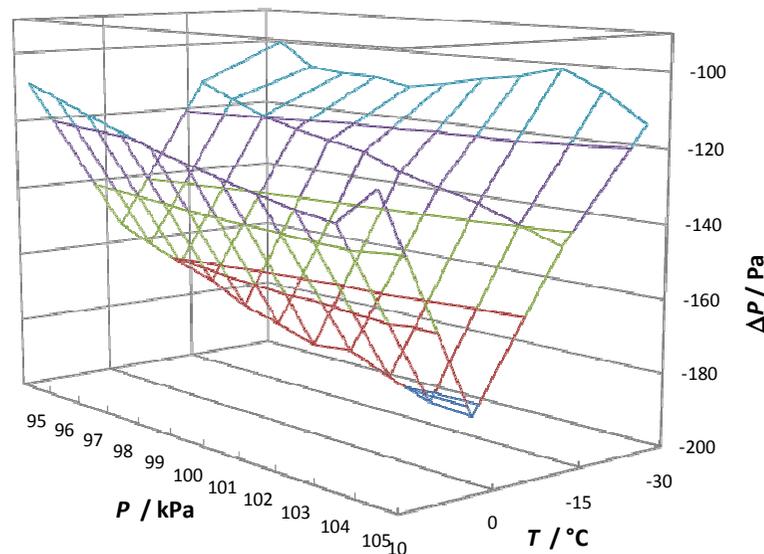




Calibration curves

$$T_c(T) = T - \Delta T(T) = T + a + bT + cT^2$$

| Uncertainty contribution | PT100 A | PT100 B | PT100 C |
|---------------------------------------|--|--|--|
| <i>Temperature reference</i> | 0.011 $^\circ\text{C}$ | 0.011 $^\circ\text{C}$ | 0.011 $^\circ\text{C}$ |
| <i>Chamber uniformity</i> | 0.006 $^\circ\text{C}$ | 0.009 $^\circ\text{C}$ | 0.019 $^\circ\text{C}$ |
| <i>Sensor under calibration</i> | 0.007 $^\circ\text{C}$ | 0.008 $^\circ\text{C}$ | 0.014 $^\circ\text{C}$ |
| <i>Calibration curve</i> | 0.026 $^\circ\text{C}$ | 0.017 $^\circ\text{C}$ | 0.018 $^\circ\text{C}$ |
| Standard Uncertainty | 0.029 $^\circ\text{C}$ | 0.022 $^\circ\text{C}$ | 0.026 $^\circ\text{C}$ |
| Expanded Uncertainty (k=2) | 0.058 $^\circ\text{C}$ | 0.044 $^\circ\text{C}$ | 0.052 $^\circ\text{C}$ |



$$P_c(P, T) = P + a + bP + cT + dPT + eT^2$$

| Uncertainty contribution | |
|---------------------------------------|--------------|
| <i>Pressure reference</i> | 0.3 Pa |
| <i>Chamber uniformity</i> | 2.5 Pa |
| <i>Sensor under calibration</i> | 0.3 Pa |
| <i>Calibration curve</i> | 26 Pa |
| Standard Uncertainty | 26 Pa |
| Expanded Uncertainty (k=2) | 52 Pa |

The climate Change Tower in Ny Alesund



May – October 2017 metrology campaigns

4 temperature sensors and one barometer of the CCT were dismantled together with the logger.

The instruments were calibrated between $-25\text{ }^{\circ}\text{C}$ and $+15\text{ }^{\circ}\text{C}$ and from 90 kPa to 110 kPa.

Permafrost sensors calibrated in October



CCT sensors readings in calibration chamber

