Introduction to upper air measurements with radiosondes and other in situ observing systems [2]

Factors affecting comparisons with remote sensing,

Some results from WMO Comparison Tests

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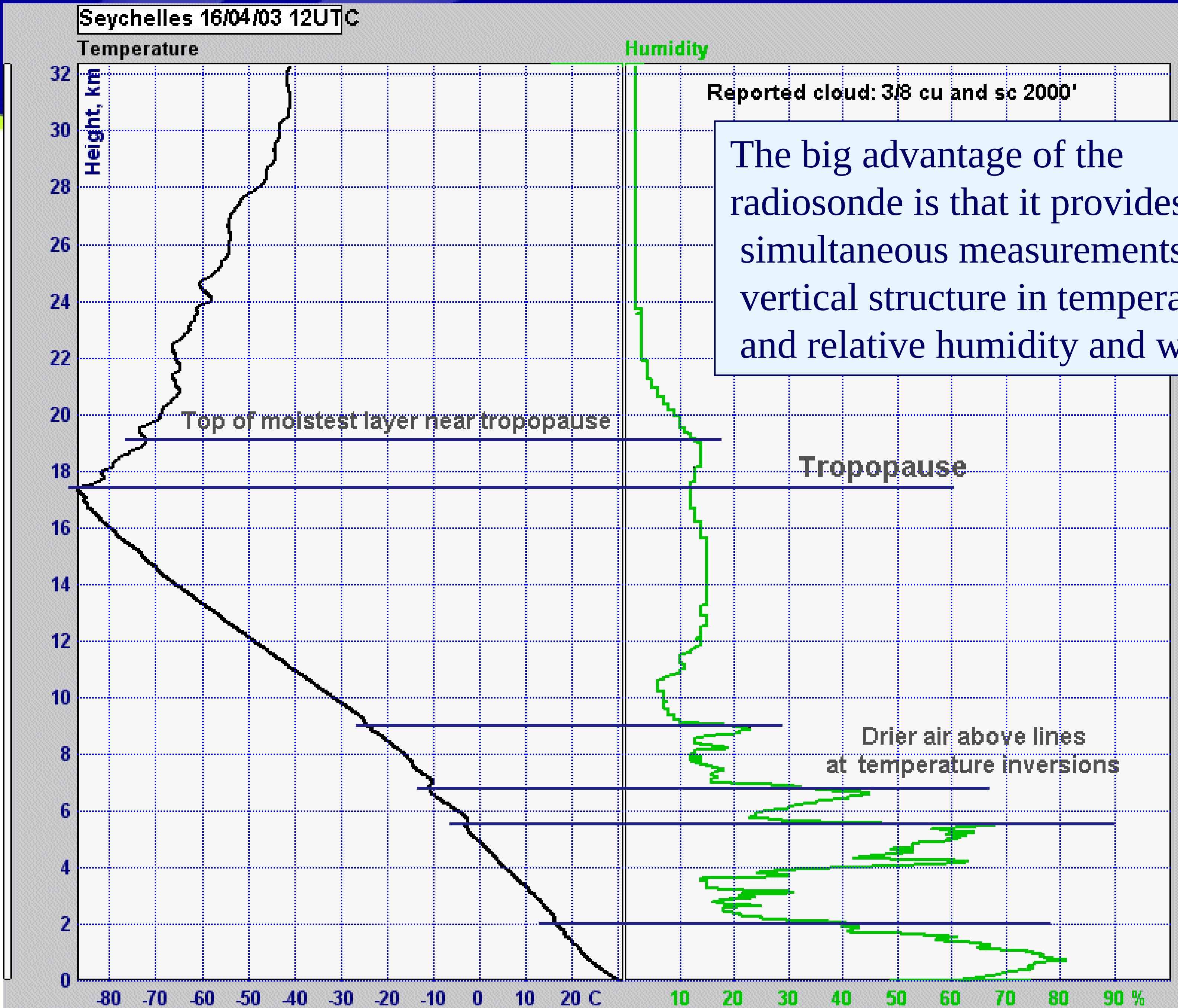
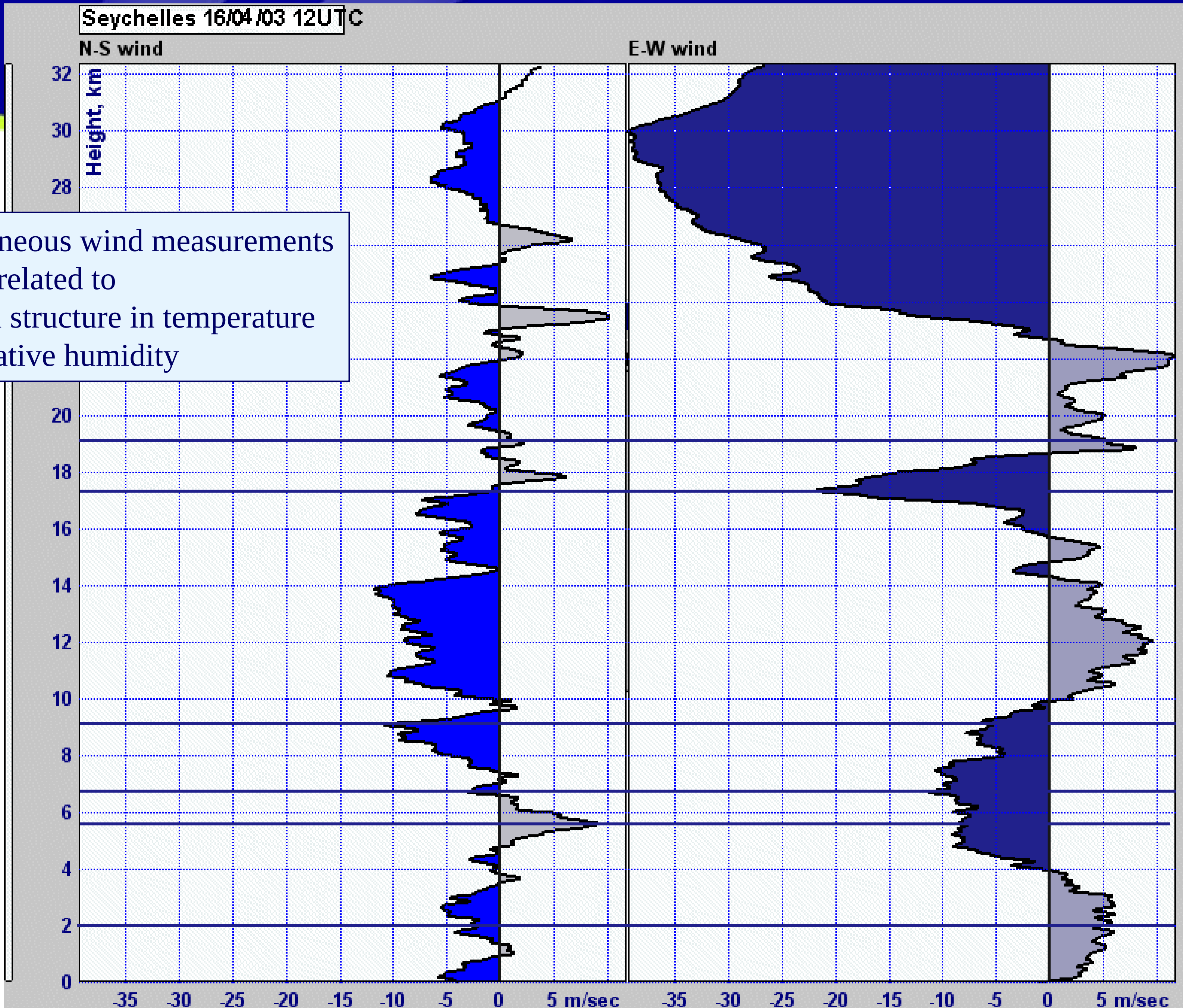
Sampling provided by radiosondes

- Examples of radiosonde profiles from Seychelles
- Profiles on a day when cold pools affected thunderstorm development in southern England
- Detailed profiles from a test campaign in Camborne, 2007 separated by 3 hours.
- Closely spaced time series of radiosondes on a day with unstable boundary layer, but with capping inversion height changing with time.
- Comparison with wind profiler samples at South Uist, UK.



The big advantage of the radiosonde is that it provides simultaneous measurements of vertical structure in temperature and relative humidity and winds

Simultaneous wind measurements can be related to vertical structure in temperature and relative humidity



- **Radiosondes measure the conditions in a small volume of air very accurately. However, most users require an average value over larger areas**

- **In practice, the differences with time of day and location for temperature and winds are usually small over relatively flat areas and justify using the radiosonde to represent larger volumes of the air mass, without large error.**

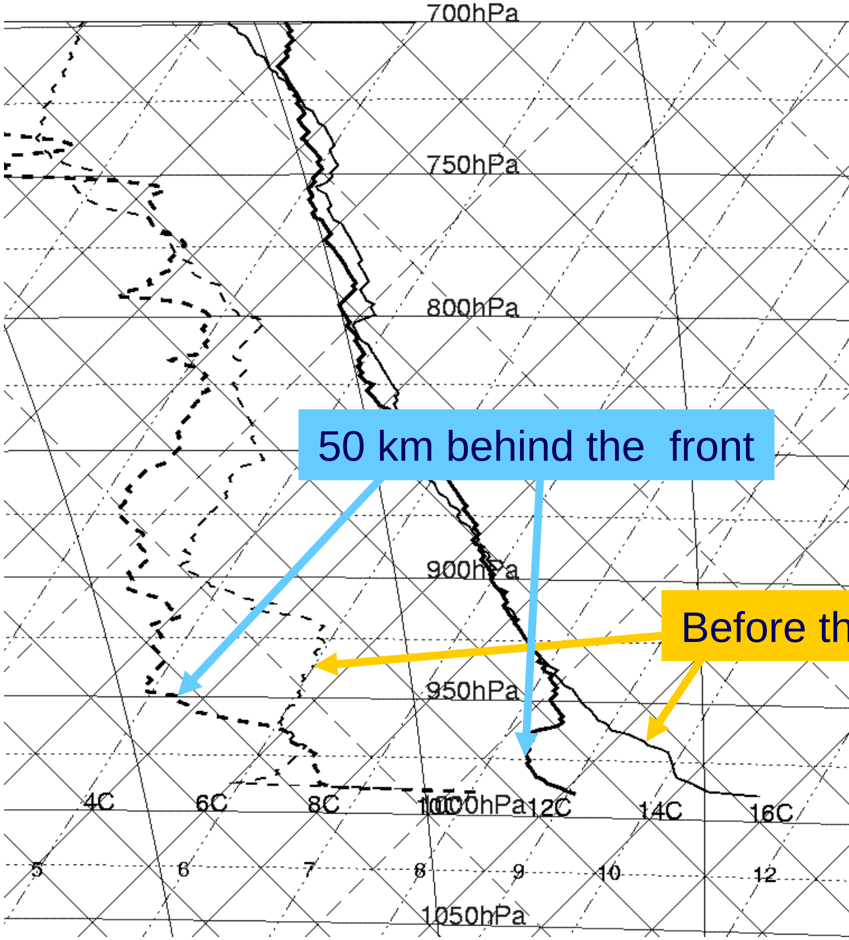
- **But this is often not true when significant weather is present and here one radiosonde sample on its own or even many radiosondes will not be adequate, see next slide.**

- **Often a combination of radiosondes given precise profiles and remote sensing showing the time continuity is the optimum observing mix, and this has to be explored further in expected upper air network design experiments.**

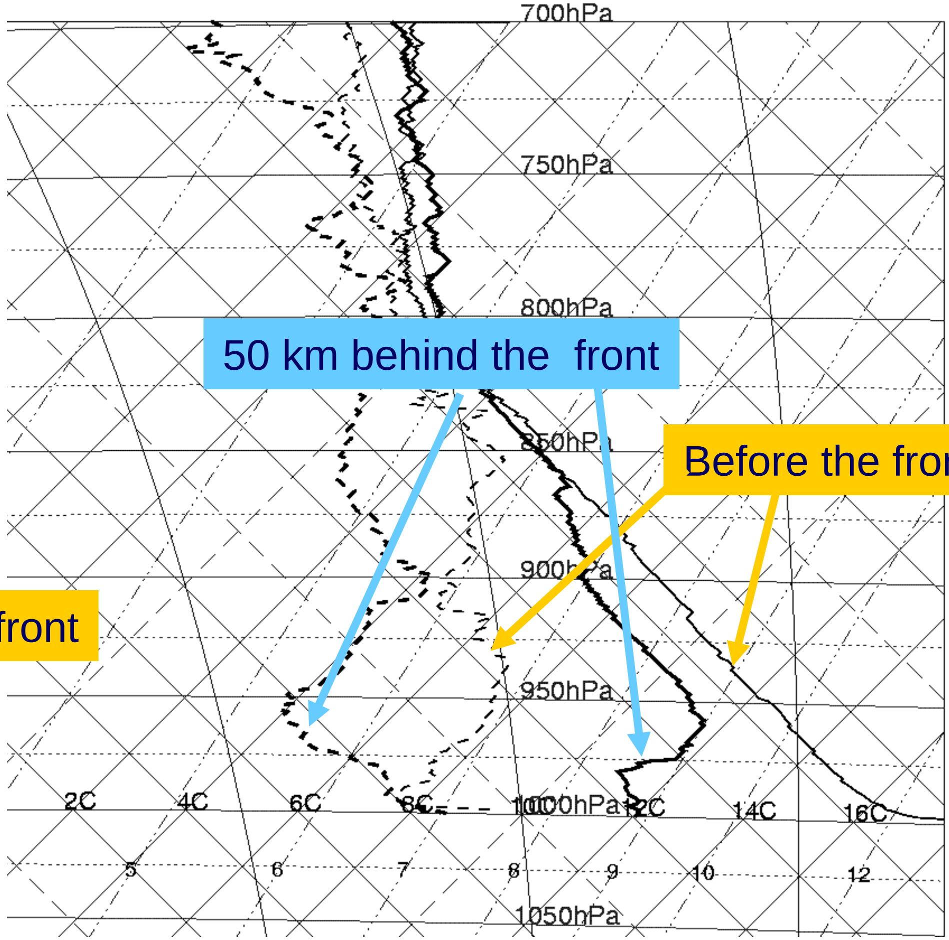
Radiosondes from CSIP

- The next slide shows radiosondes measurements from the CSIP experiment in the Uk in 2005.
- On the particular day special radiosondes were launched at about 3 hour intervals from several sites, but the measurements shown here were from a site close to the coast, Preston Farm, and a site 70 km further north at Larkhill.
- In both cases a gust front passed the site and a radiosonde was launched in the air before and behind this front, identifying the presence and depth of cold pool air behind the front.
- This cold pool propagated eastwards for some time with the front influencing the development of the convection

Here the radiosondes unambiguously resolve the vertical structure in a cold pool associated with convective development, CSIP IOP 18, P. Clarke Met Office

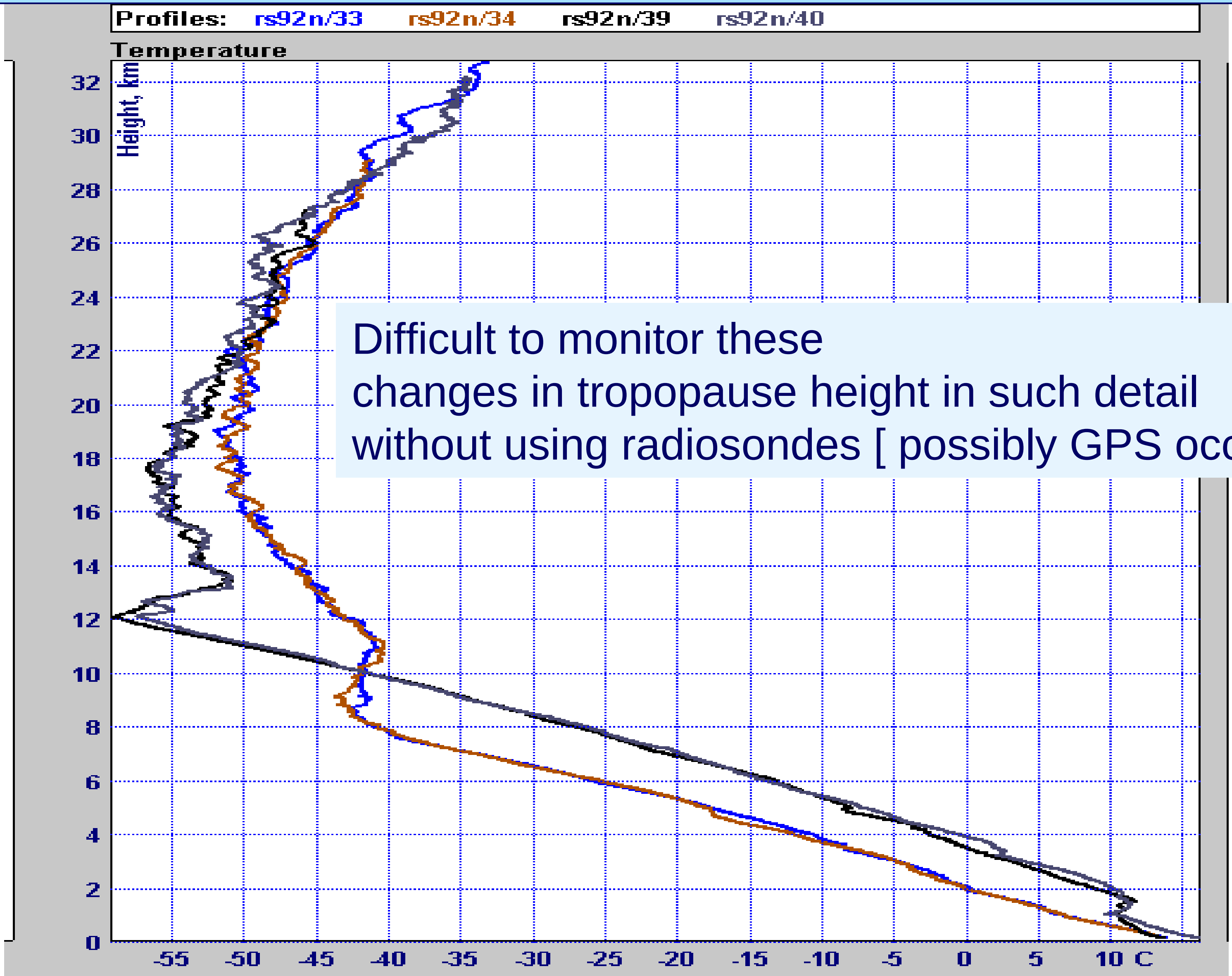


Larkhill 0957 & 1208 (bold)
70 km north of Preston farm)



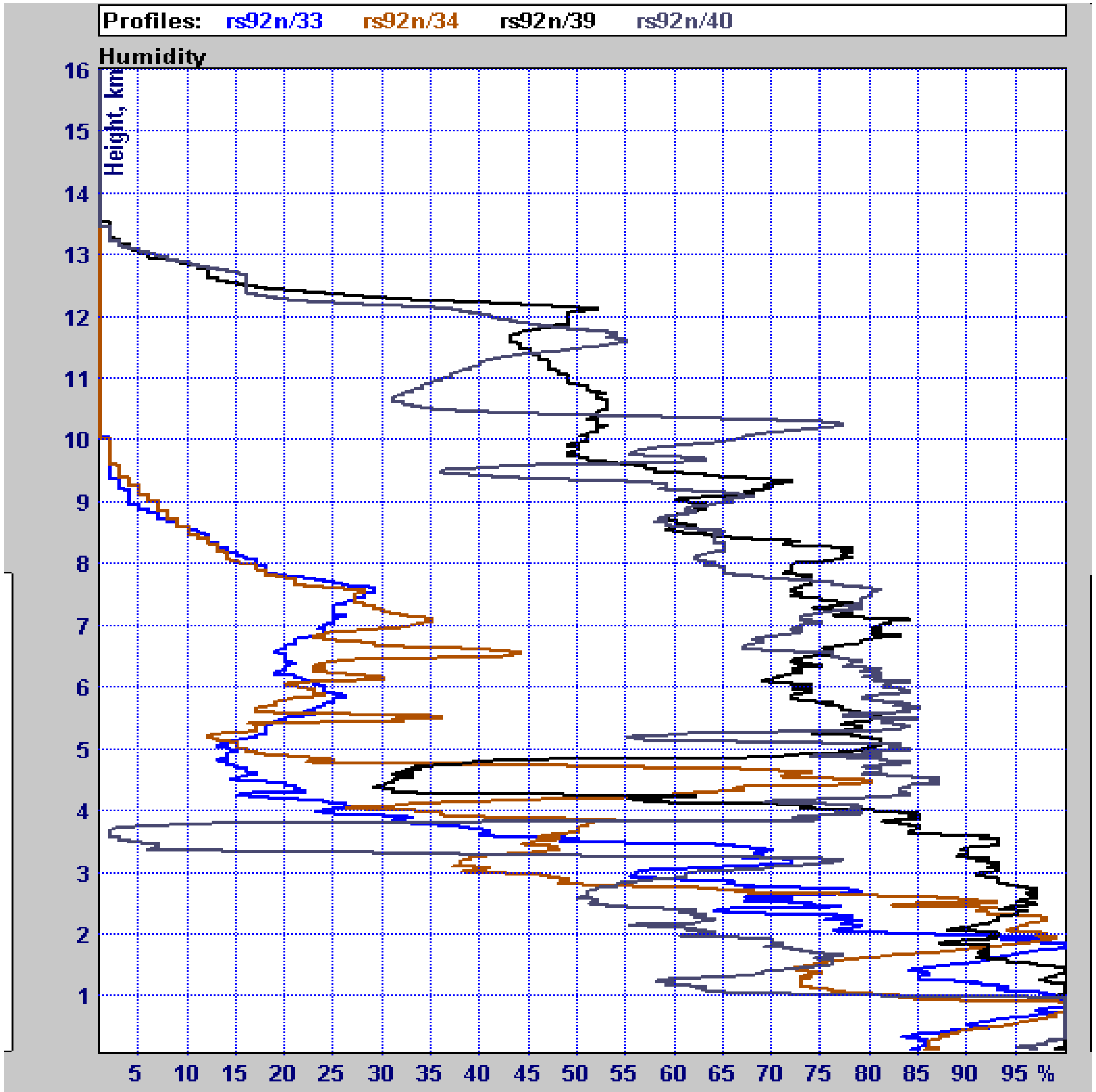
Preston Farm 1200 & 1300 (bold)

Examples of radiosonde measurements 4 hours apart, Camborne , On 03 July and 05 July 2007, showing the limitations imposed by smaller scale temperature fluctuations in the stratosphere



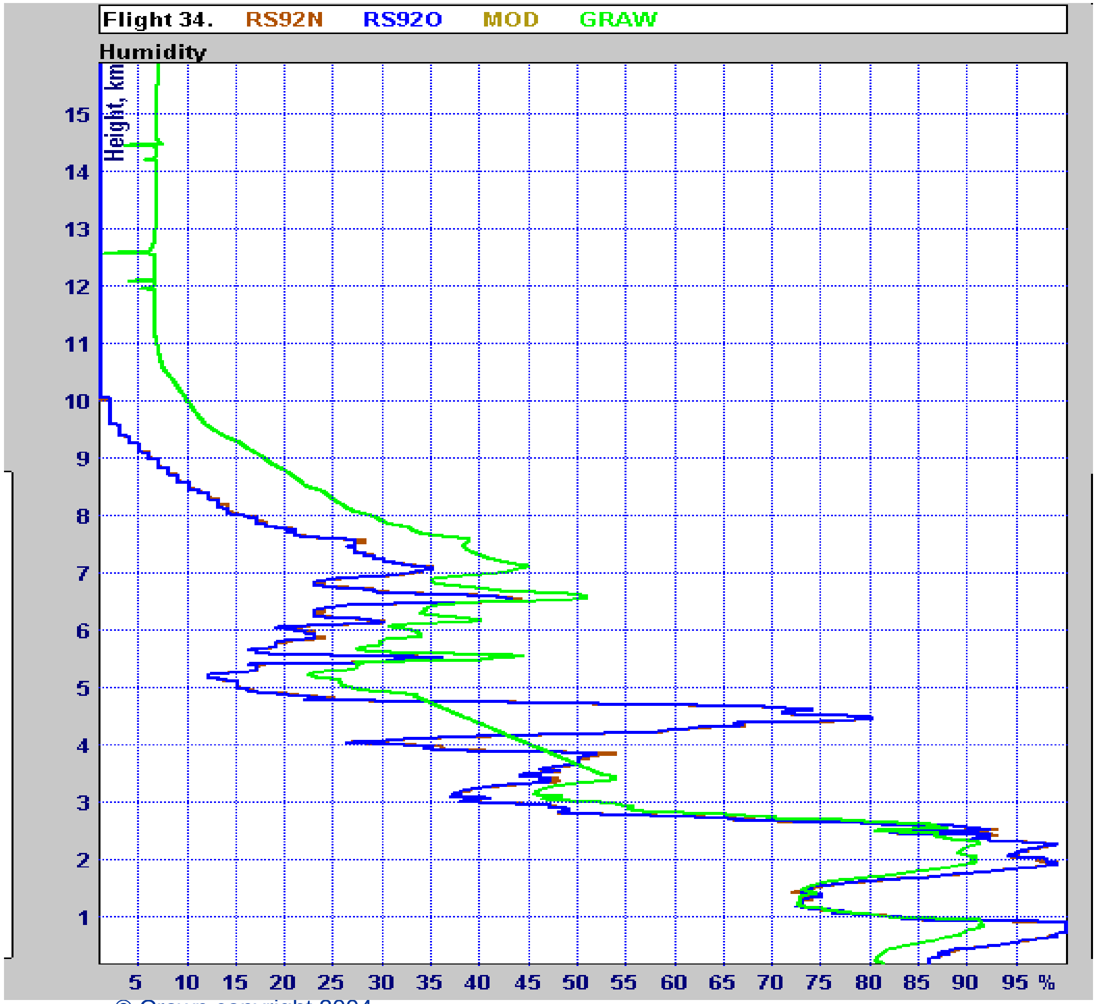
Difficult to monitor these
changes in tropopause height in such detail
without using radiosondes [possibly GPS occultation?]

Examples of radiosonde measurements 4 hours apart, Camborne , On 03 July and 05 July 2007, showing the limitations imposed by smaller scale relative humidity changes in the troposphere



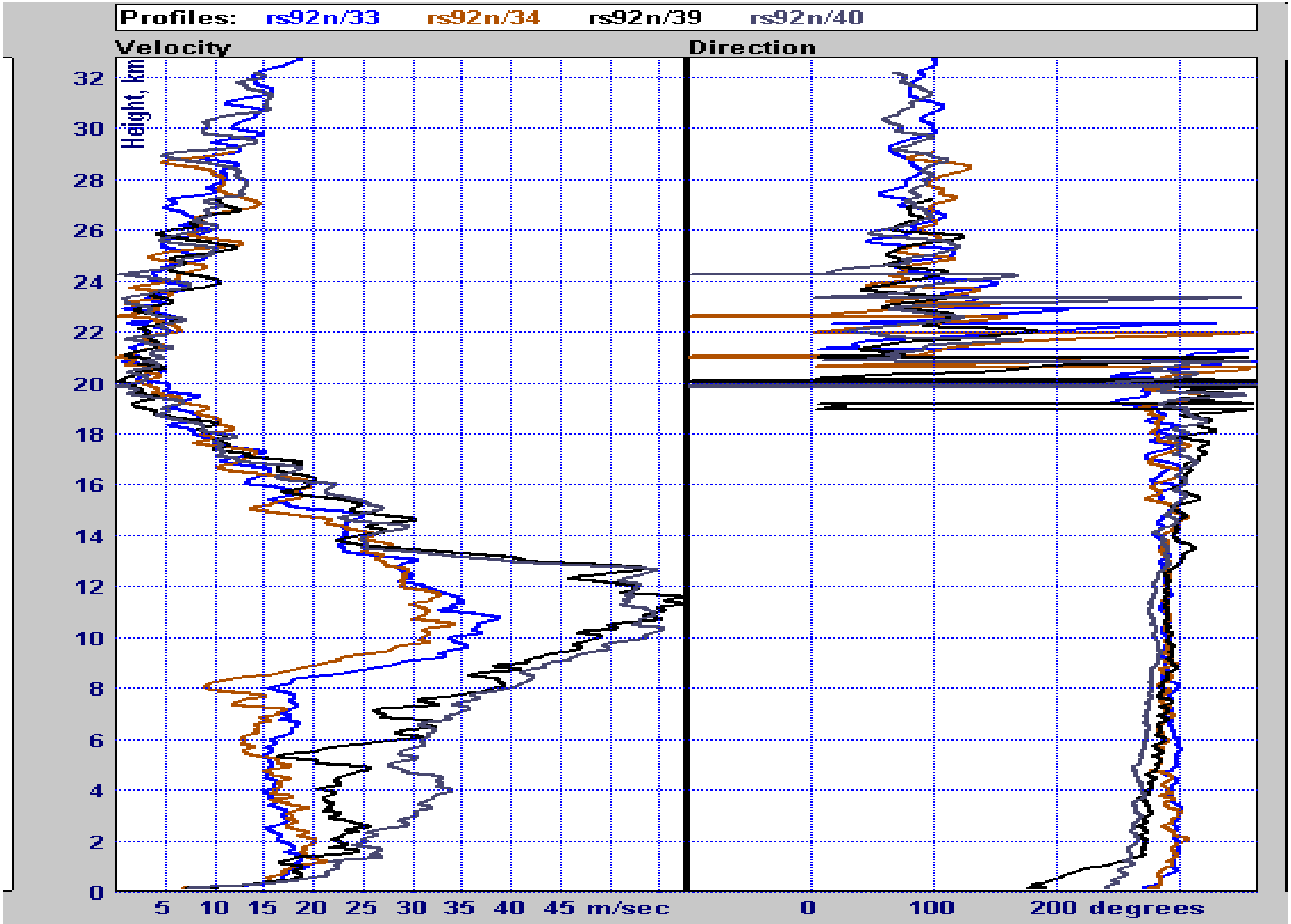
Obtaining an accurate Representation of 3 dimensional water vapour distribution requires combination of measurements from many different types of systems and radiosondes offer a cheap and mobile system which needs little post processing.

Example of simultaneous measurements by three different radiosondes, [between 3.5 and 5 km, the Graw radiosonde was not reporting data on this flight], but agreement between the two at other levels shows small scale vertical structure is not spurious. The differences between the two Vaisala radiosondes [RS92O and RS92N] are so small that it is difficult to distinguish the two measurements



Radiosondes have always been able to measure the location of hydrolapses in the vertical, but now Vaisala radiosondes can measure the structures with a reproducibility of 1 to 2 per cent, see the example here so the main work is to identify possible sources of systematic error, such as hysteresis, contamination In cloud , solar heating, But comparison of measurements with dew point hygrometers in the lower levels, suggests Systematic errors are less than 3 per cent at night and perhaps larger in the day.

Examples of radiosonde measurements 4 hours apart, Camborne , On 03 July and 05 July 2007, showing the limitations imposed by smaller scale wind fluctuations in the stratosphere , and the wind changes with mesoscale synoptic changes in the troposphere



Time series of radiosonde observations from CSIP

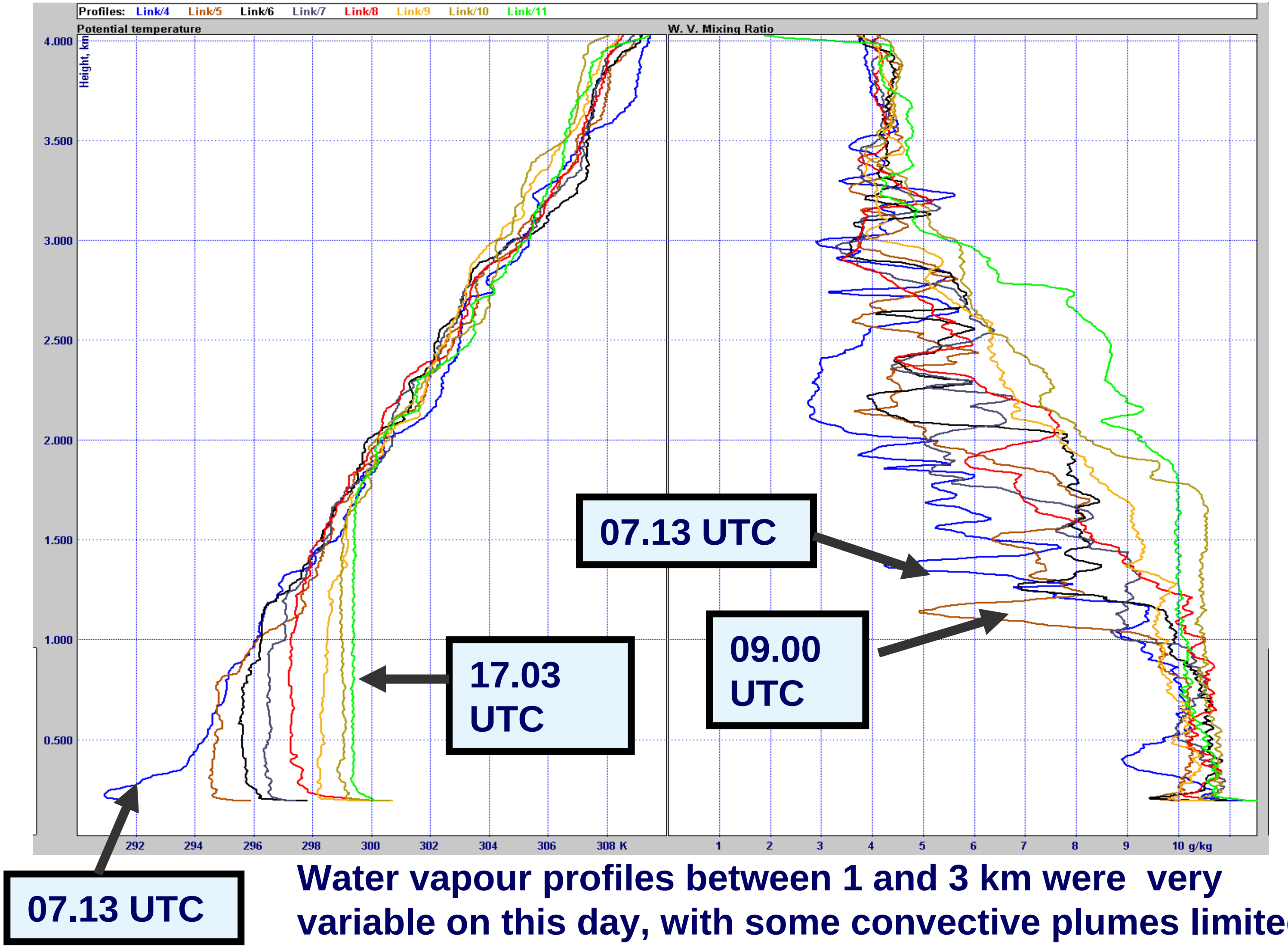
- The next slide shows a series of radiosonde measurements in the lower troposphere on a day where the boundary layer was stable to start and then the main low level hydrolapse lowered from 1.3 km to 1.1 km between 07 and 09 UTC

- How much of the small scale detail in the radiosonde measurement is relevant to the structure of the signal to noise profiles measured at 1.29 GHz by the wind profiler.

- In the second slide the original radiosonde data has been smoothed to some extent to see if the refractive index gradients calculated then correlate better with the wind profiler signal structure. [certainly the relative humidity structures for the 2 km above the main hydrolapse seem to require some smoothing.
  (work performed by Catherine Gaffard)

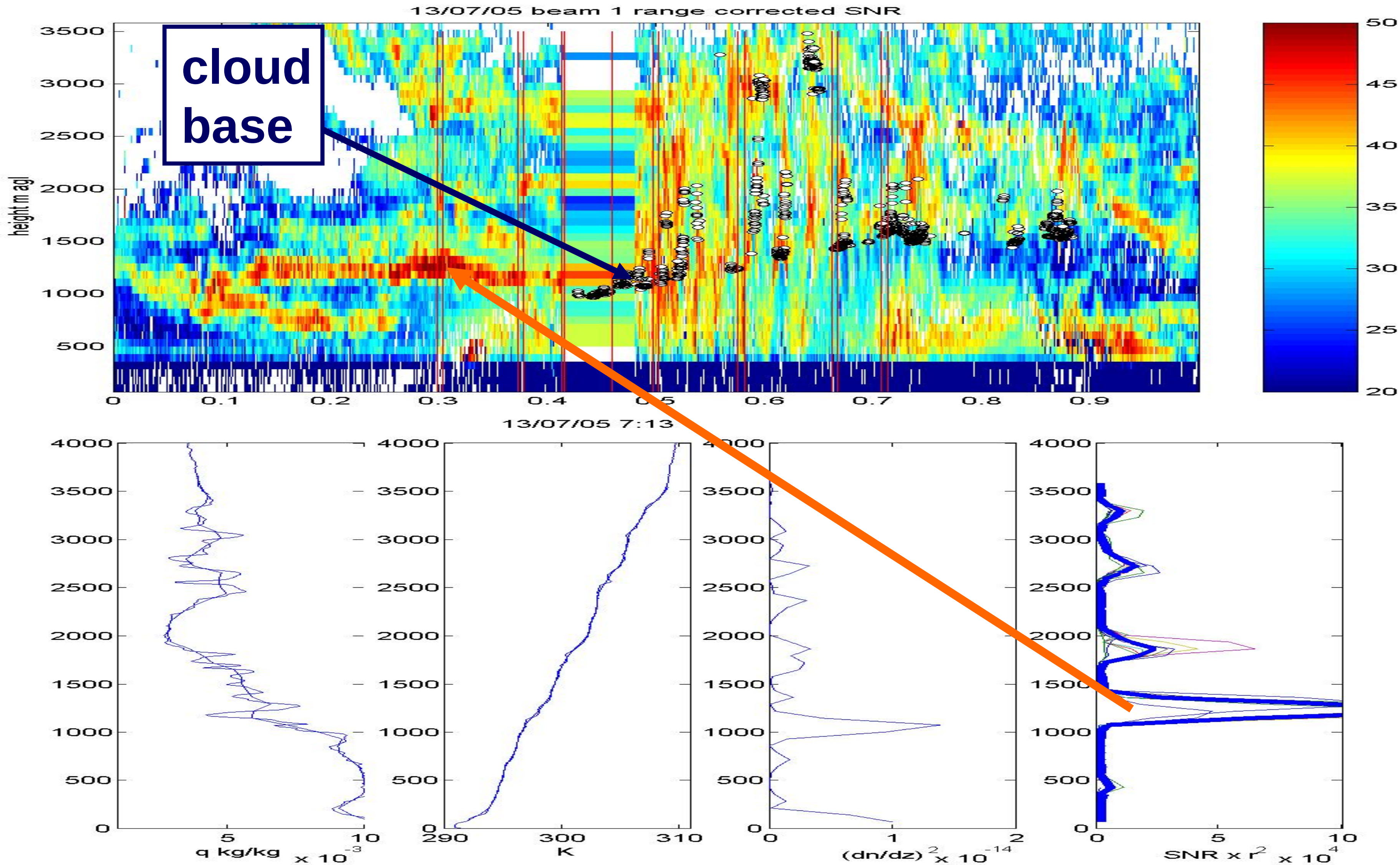
- So here the main benefit is using the information from the radiosonde and remote sensing to understand the nature of the changes in the atmospheric profiles during the day.

Radiosonde Measurements at 07.13, 09.00, 10.00, 11.00,12.00,13.53, 15.57,17.03 at Linkenholt, Hants,13 July 2005, after C. Gaffard.



Water vapour profiles between 1 and 3 km were very variable on this day, with some convective plumes limited by lids at 1.5 and 2 km, and others limited at about 3 km.

13/07/05 CSIP IOP example of cap and then broken lid. (could lead to deep convection) wind profiler shows evidence for high variability with time in the atmospheric profiles after 12 UTC.



Height of main hydrolapse reliably identified

Use of radiosondes to verify wind profiler measurements

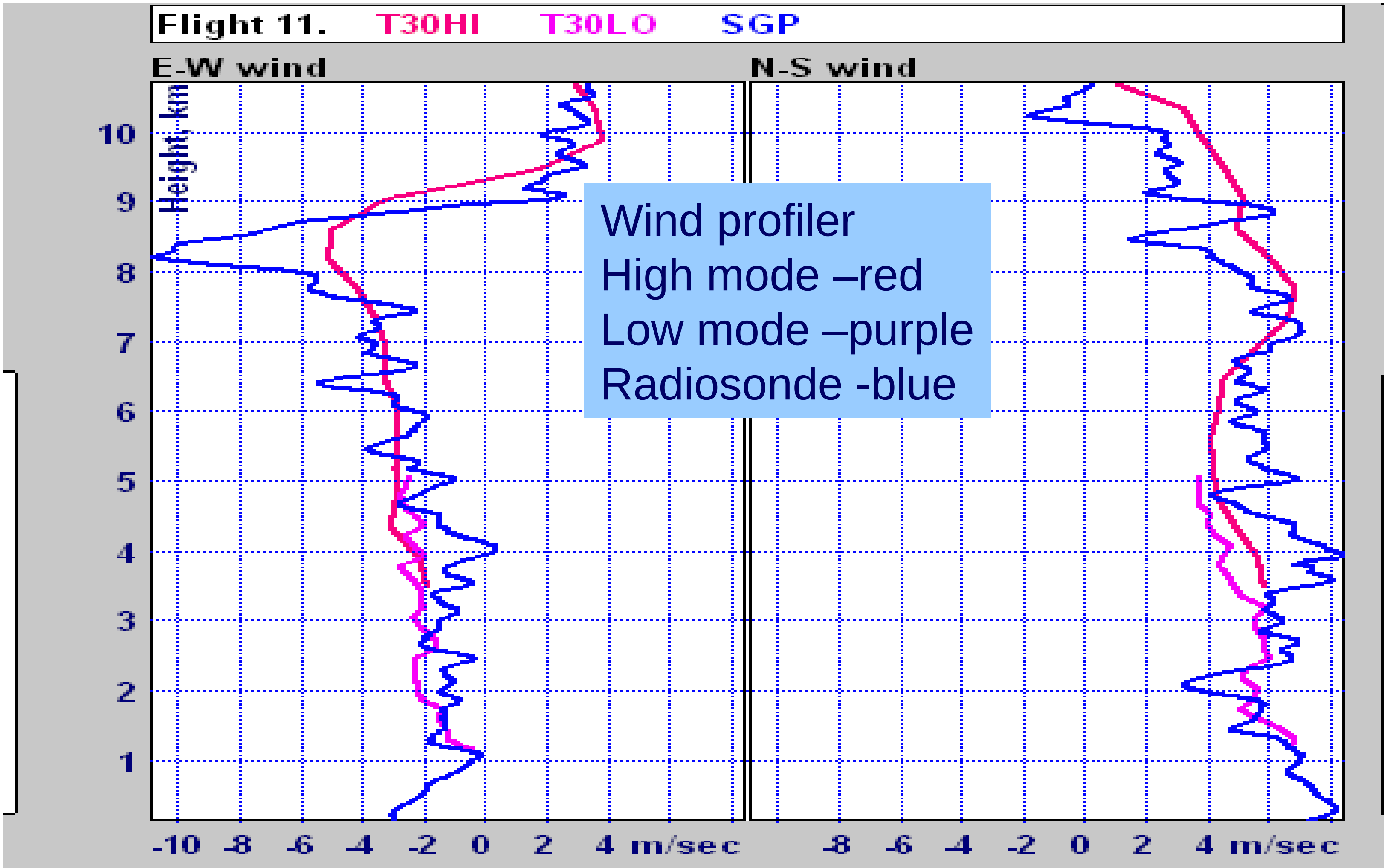
- In the next two slides , radiosondes specially launched from near the wind profiler site at South Uist are compared with the wind profiler measurements

- In many similar studies differences between the systems are attributed to the different sample volumes between the wind profiler and the radiosonde.

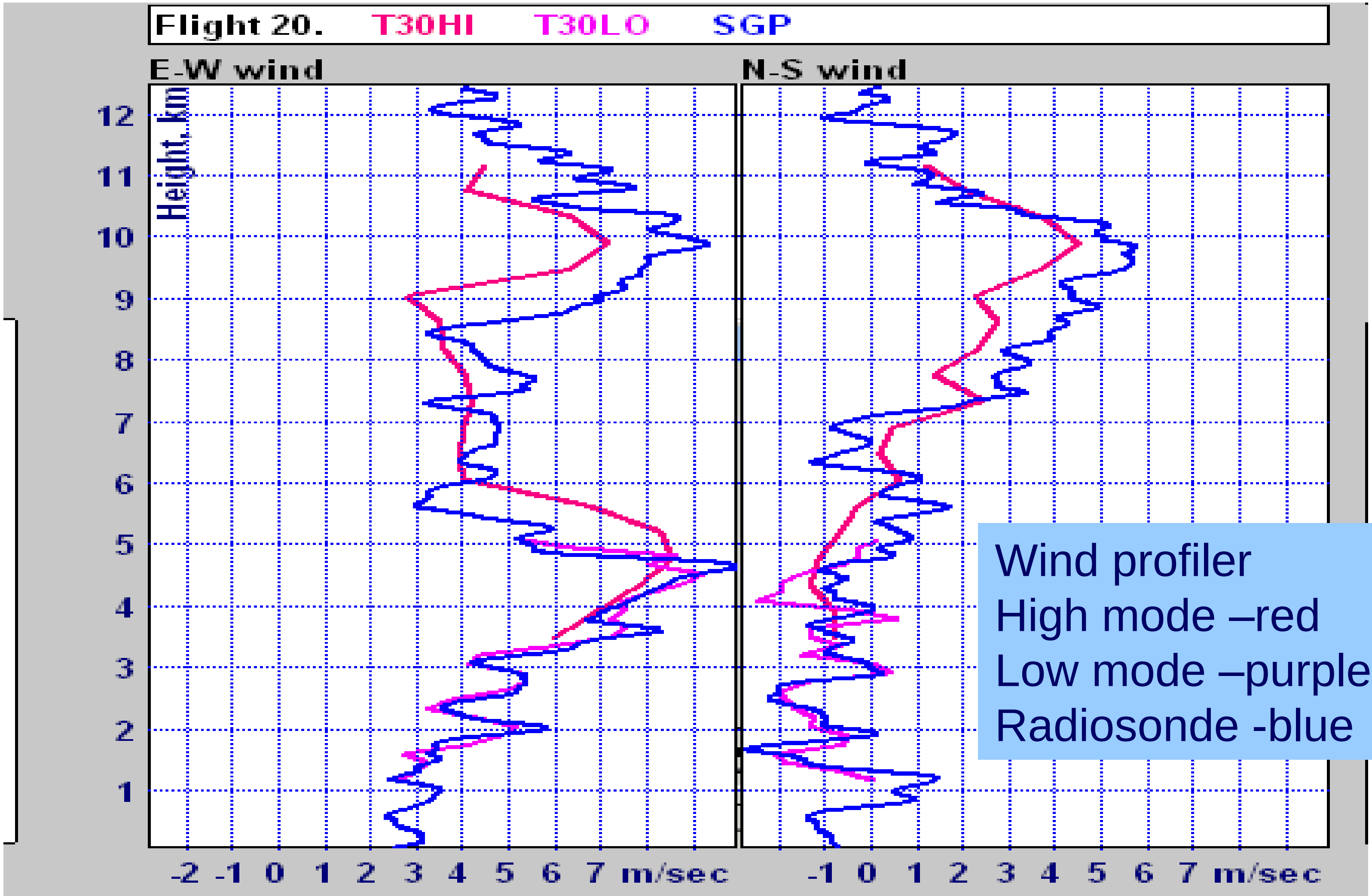
- However in this test, the standard deviation between the radiosonde and wind profiler measurements were as expected from the expected error estimates of the two systems and there was no serious increase in random differences which might have been expected if the differences between the sample volumes was producing significant differences.

- So it seems in many exercises that the different sampling volumes has been used as an excuse for not investigating potential deficiencies in the remote sensing

Wind profiler winds with collocated radiosonde winds.
The the winds were low so vertical structure should be seen by both at similar heights. The wind profiler high mode vertical resolution seems poorer than was expected, but this needed to be cross checked on several occasions , before the result could be trusted, given the radiosonde sample may only represent a very limited area.



Comparison of wind profiler winds with collocated radiosonde winds, Low resolution of the high mode can in some circumstances lead to displacement of wind structure in the vertical, but several closely spaced radiosondes seem to be needed to check whether this just a random sample or significant effect.



Wind profiler
High mode –red
Low mode –purple
Radiosonde -blue

Radiosonde measurement errors

- Guide to Meteorological Instruments and Methods of Observation Seventh Edition, WMO No. 8 [contains references to published literature.]

- Also "The WMO Intercomparison of radiosonde Systems- Final Report, Vacoas, Mauritius, 2-25 February 2005"
  Instruments and Methods of Observation Report; No 83, WMO/TD 1303, 2005

- Instruments and Methods of Observation Programme Monitoring Reports,
  Upper-air monitoring statistics for 2005

http://www.wmo.ch/pages/prog/www/IMOP/monitoring.html

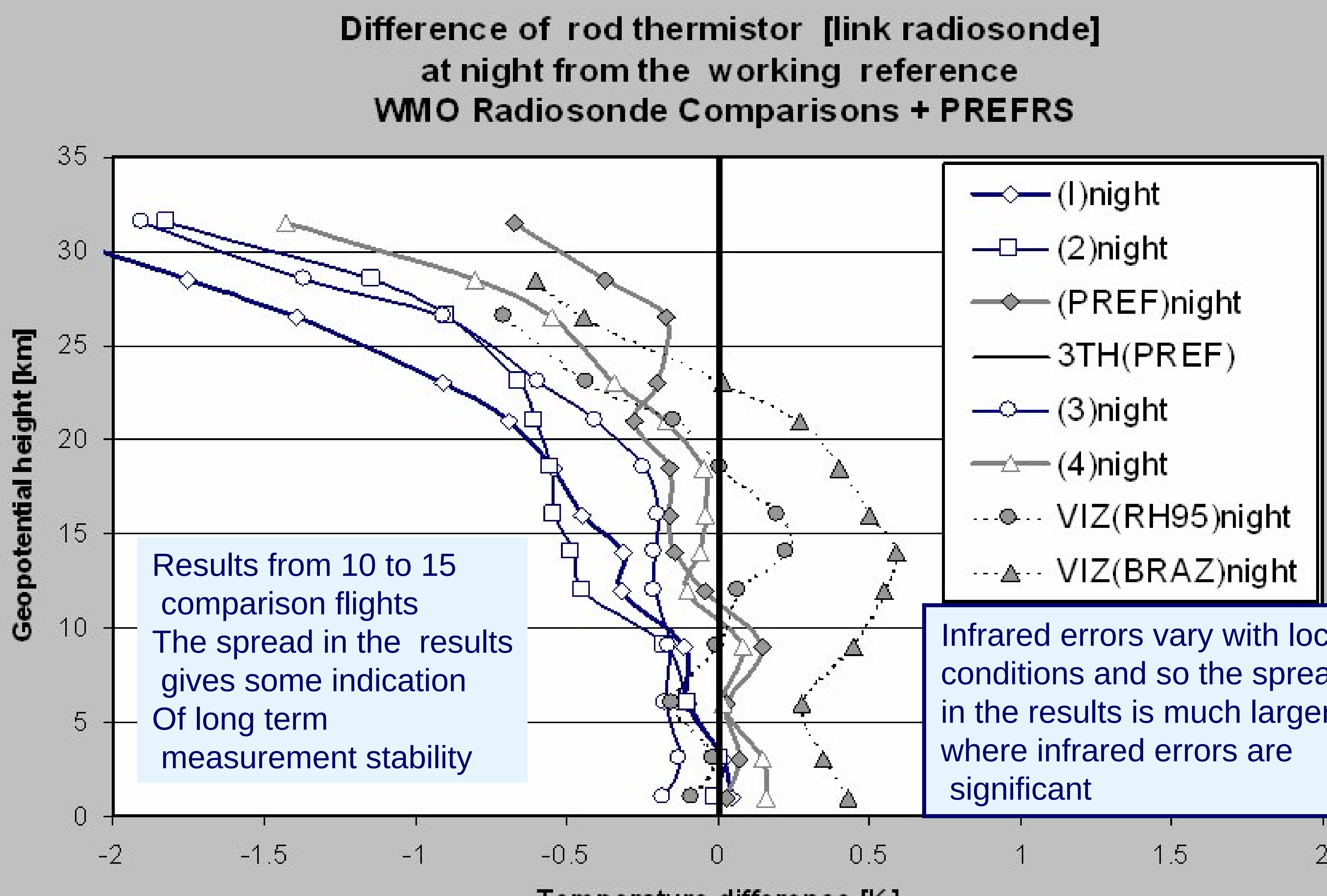
Temperature sensor errors [see CIMO Guide] for details

- Radiosonde temperature errors at night were expected to be low, but with the two most widely used better radiosondes from 1980 to 2000 this was not entirely true in the stratosphere, see the next two slides. For Vaisala the errors were relatively stable with time, but not for the rod thermistor system. Now white paint is eliminated from the best modern radiosondes .

- These errors have now been eliminated in modern radiosondes and the nighttime measurements are now well suited for all uses.

- In the daytime, solar heating has to be corrected and the accuracy to which this can be achieved is related to the magnitude of the typical solar heating error. The newest radiosonde types have much smaller heating errors and their daytime measurement accuracy is not so different from night time accuracy

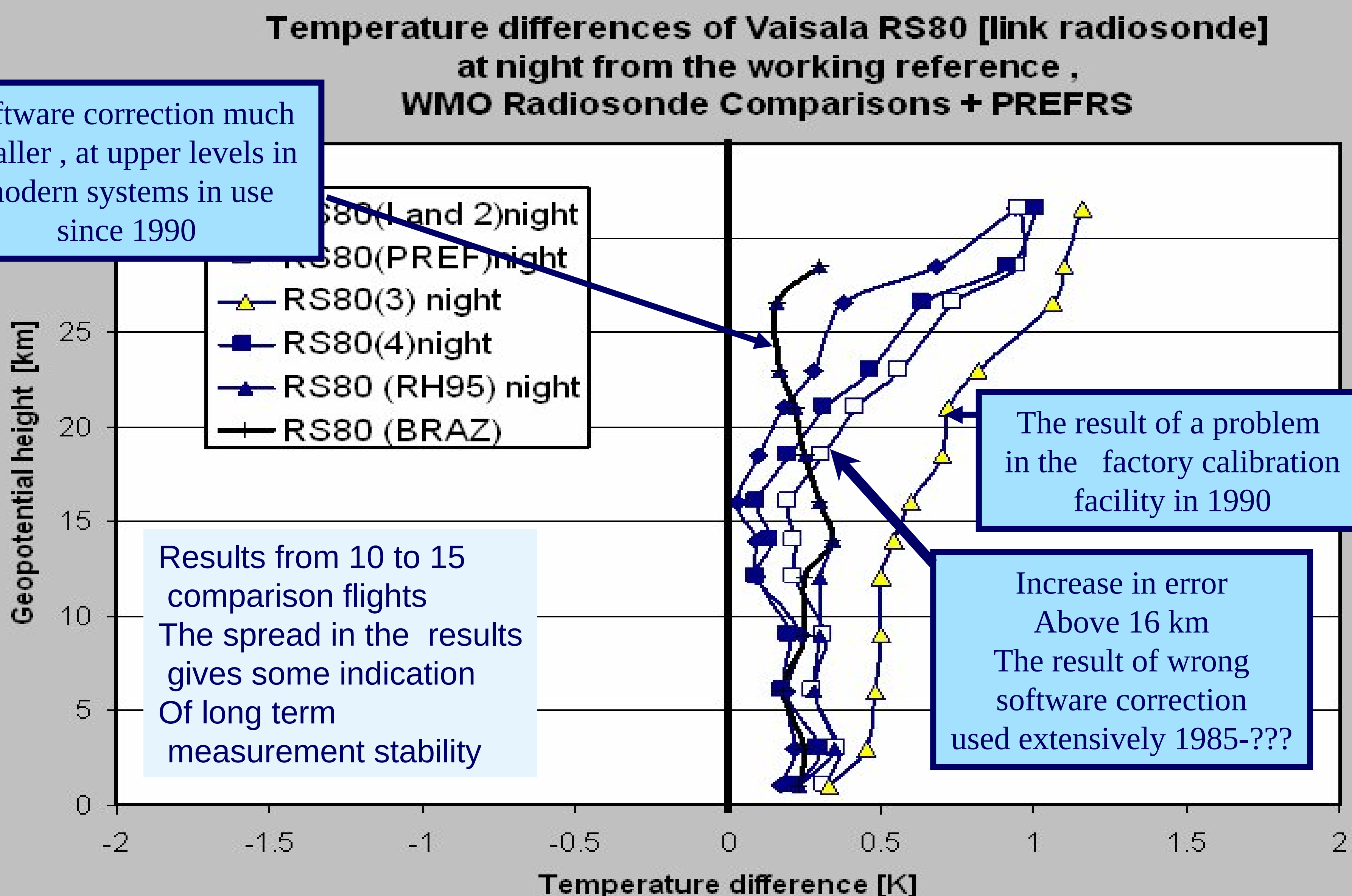
- In any case the random errors of modern radiosondes are much less than 1 deg C the value often used in data assimilation schemes and are normally closer to between 0.2 and 0.5 deg C, White paint is black in the infrared and so that the infrared radiation can generate large errors at night at upper levels



Results from 10 to 15 comparison flights
The spread in the results gives some indication
Of long term measurement stability

Infrared errors vary with local conditions and so the spread in the results is much larger where infrared errors are significant

The Vaisala RS80 sensor was aluminised and should have had small infrared radiation error, but a software correction was applied in the earlier systems that was incorrect



Software correction much smaller , at upper levels in modern systems in use since 1990

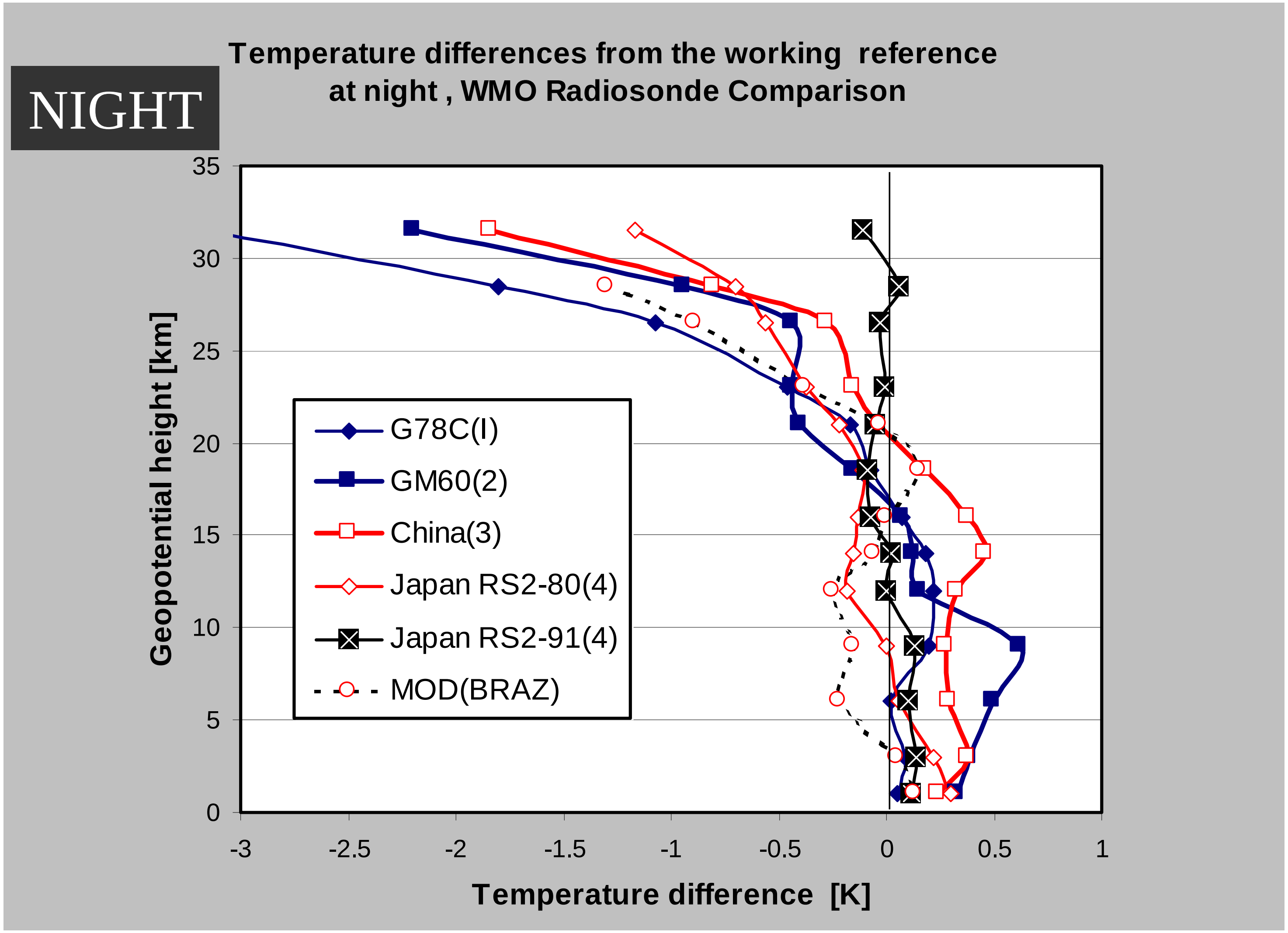
The result of a problem in the factory calibration facility in 1990

Results from 10 to 15 comparison flights
The spread in the results gives some indication
Of long term measurement stability

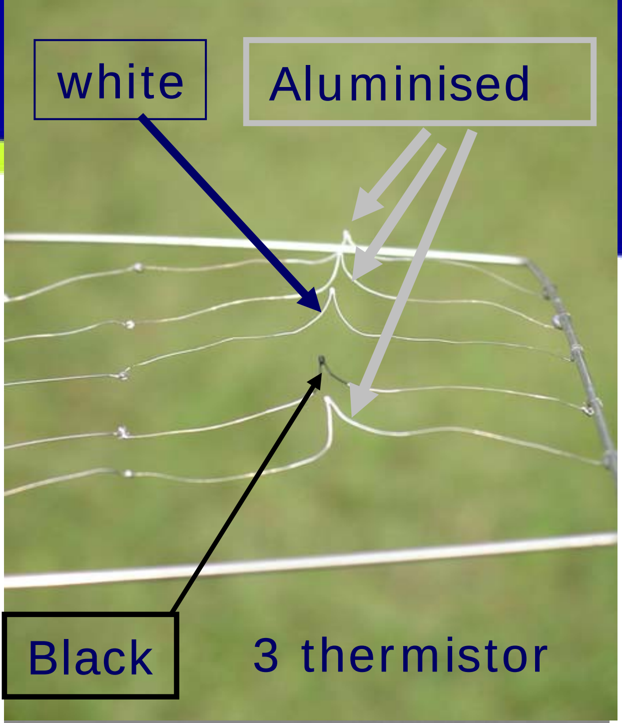
Increase in error
Above 16 km
The result of wrong software correction used extensively 1985-???

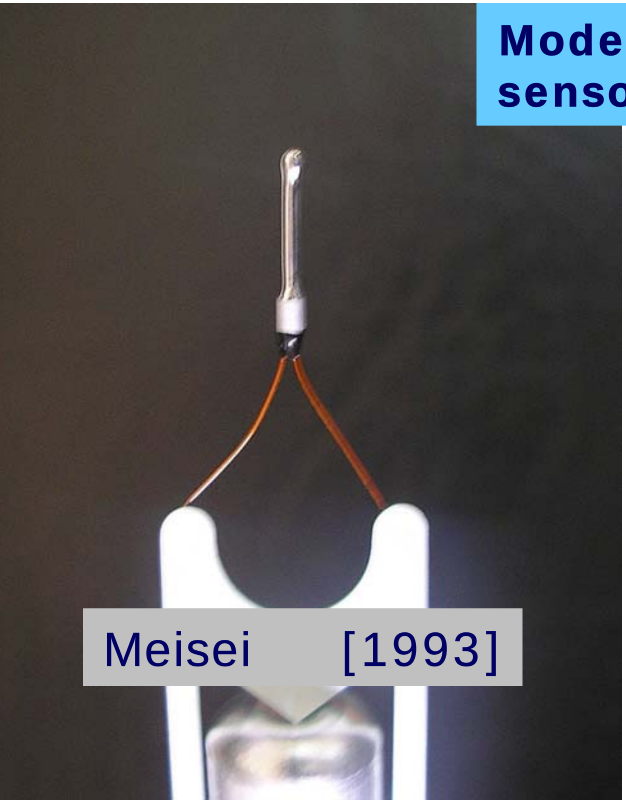
Results from other radiosondes at night [1].

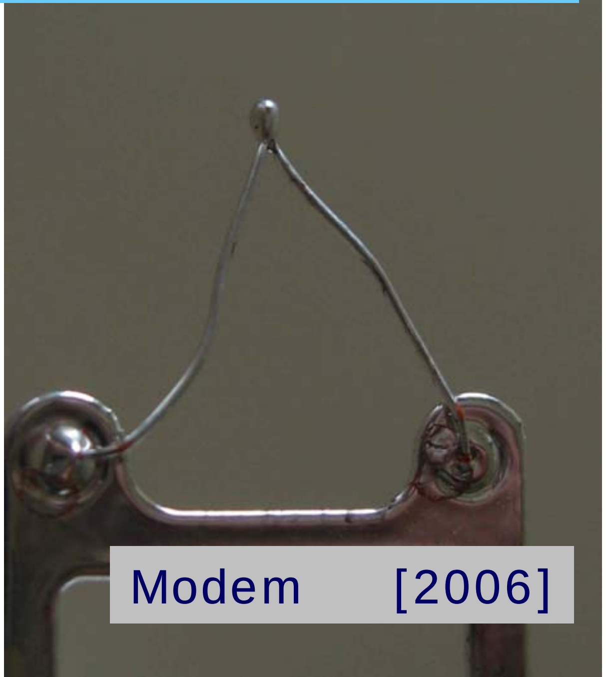
All these radiosondes show signs of infrared cooling at night , either from a white sensor or the black coating on the inside of protective ducts apart from the RS2-91 (Japan) .



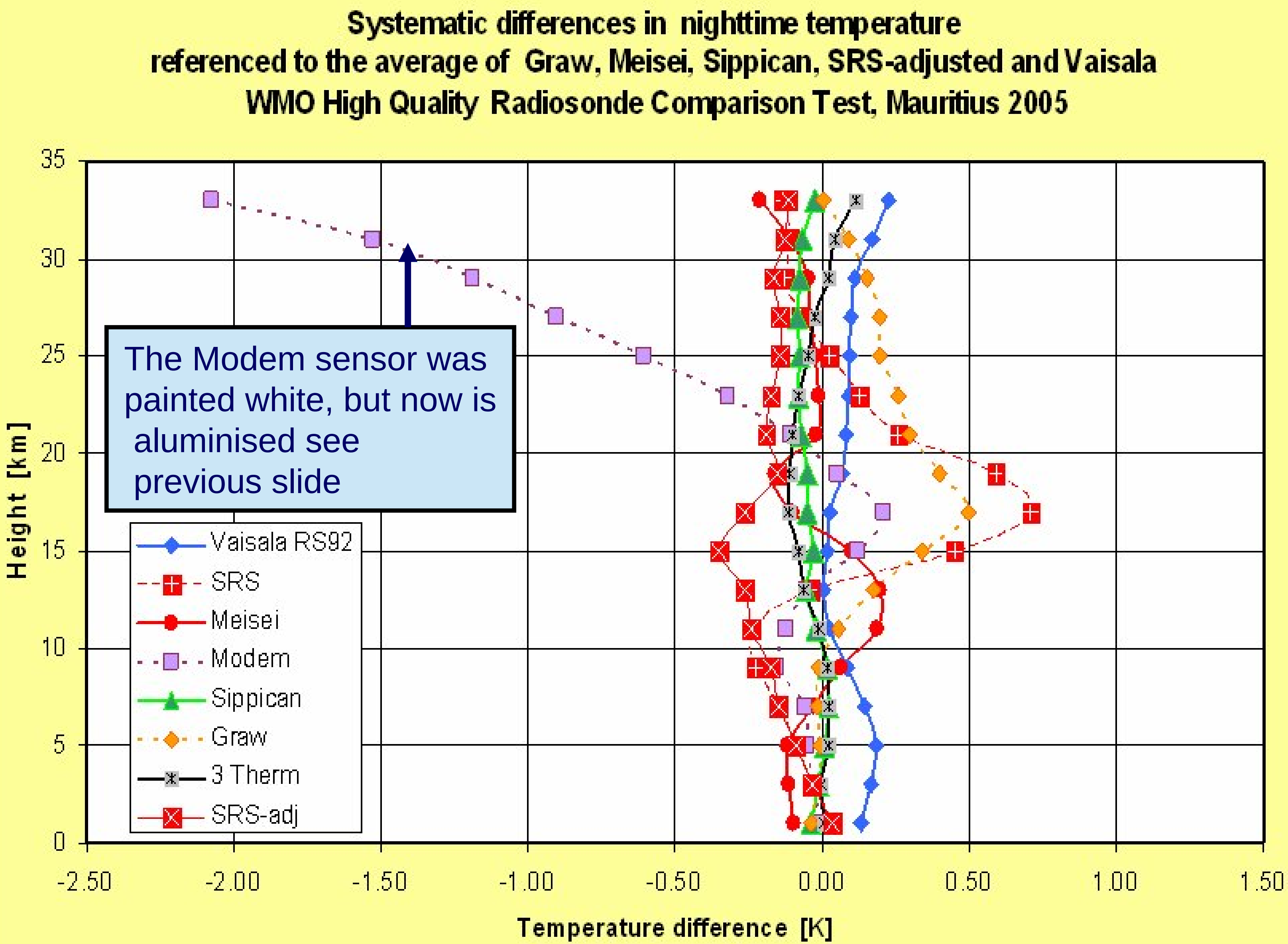
Modern Temperature sensors, [Various scales]



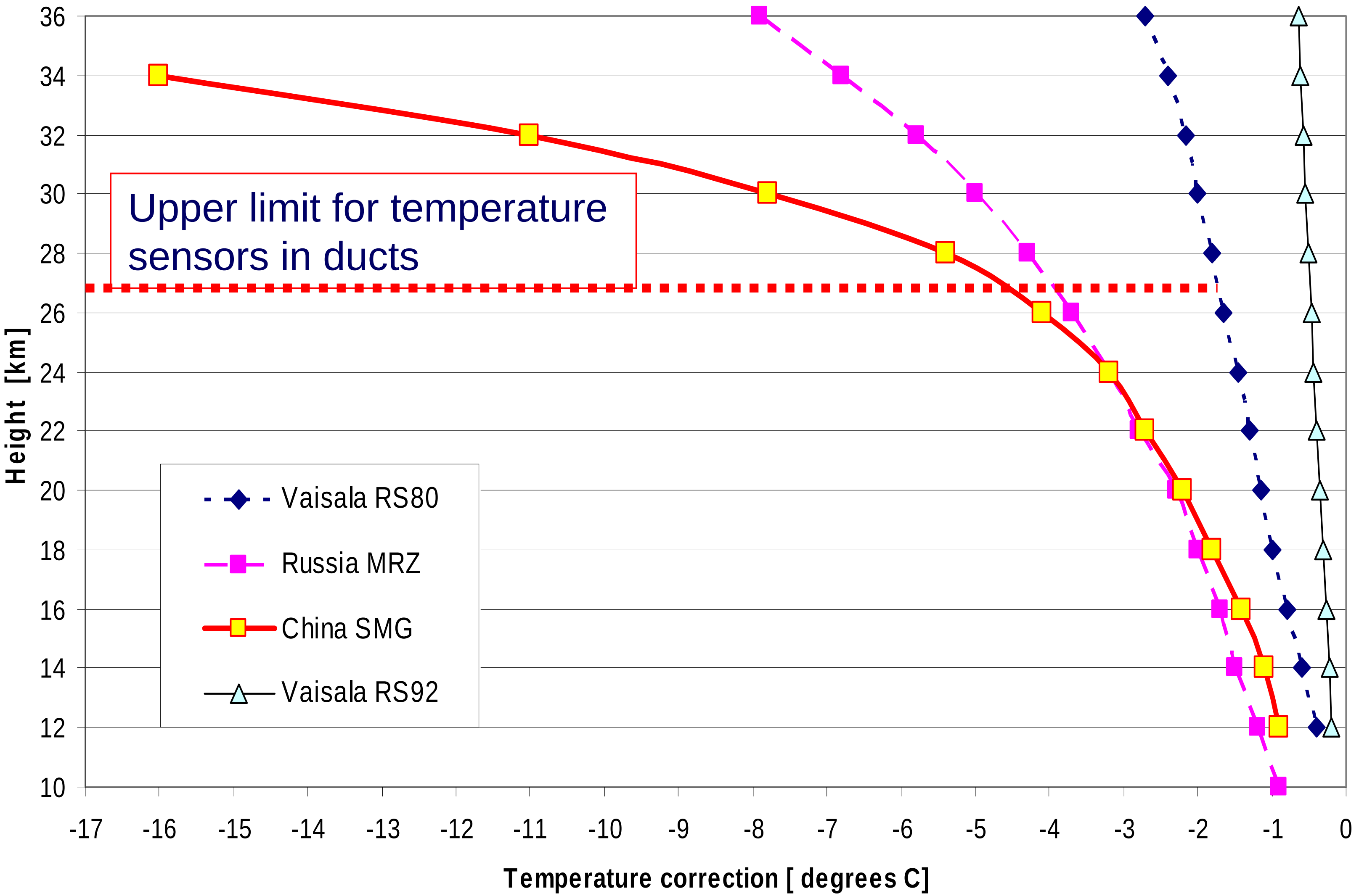




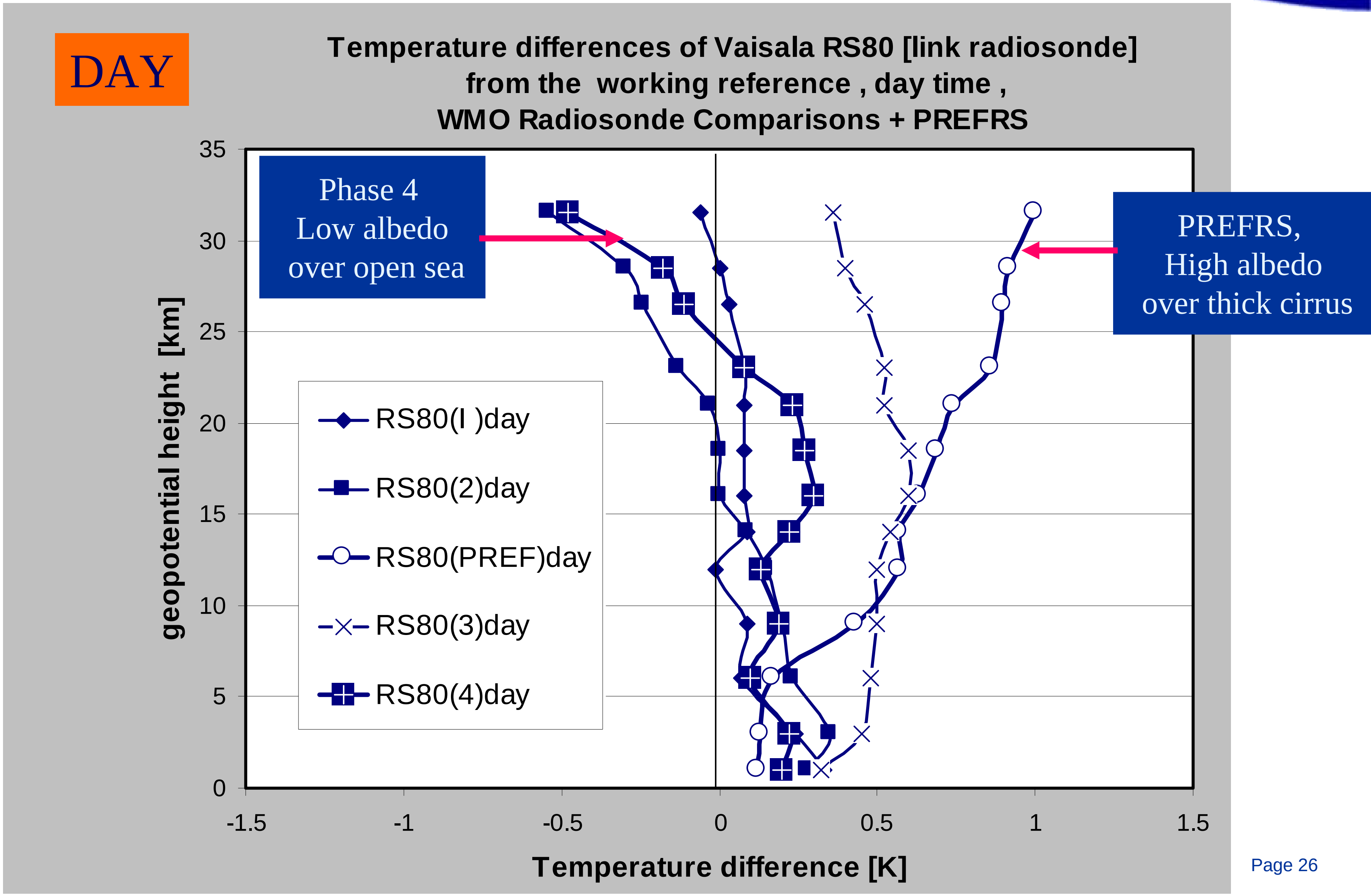
WMO- Mauritius High Quality Radiosondes -nighttime



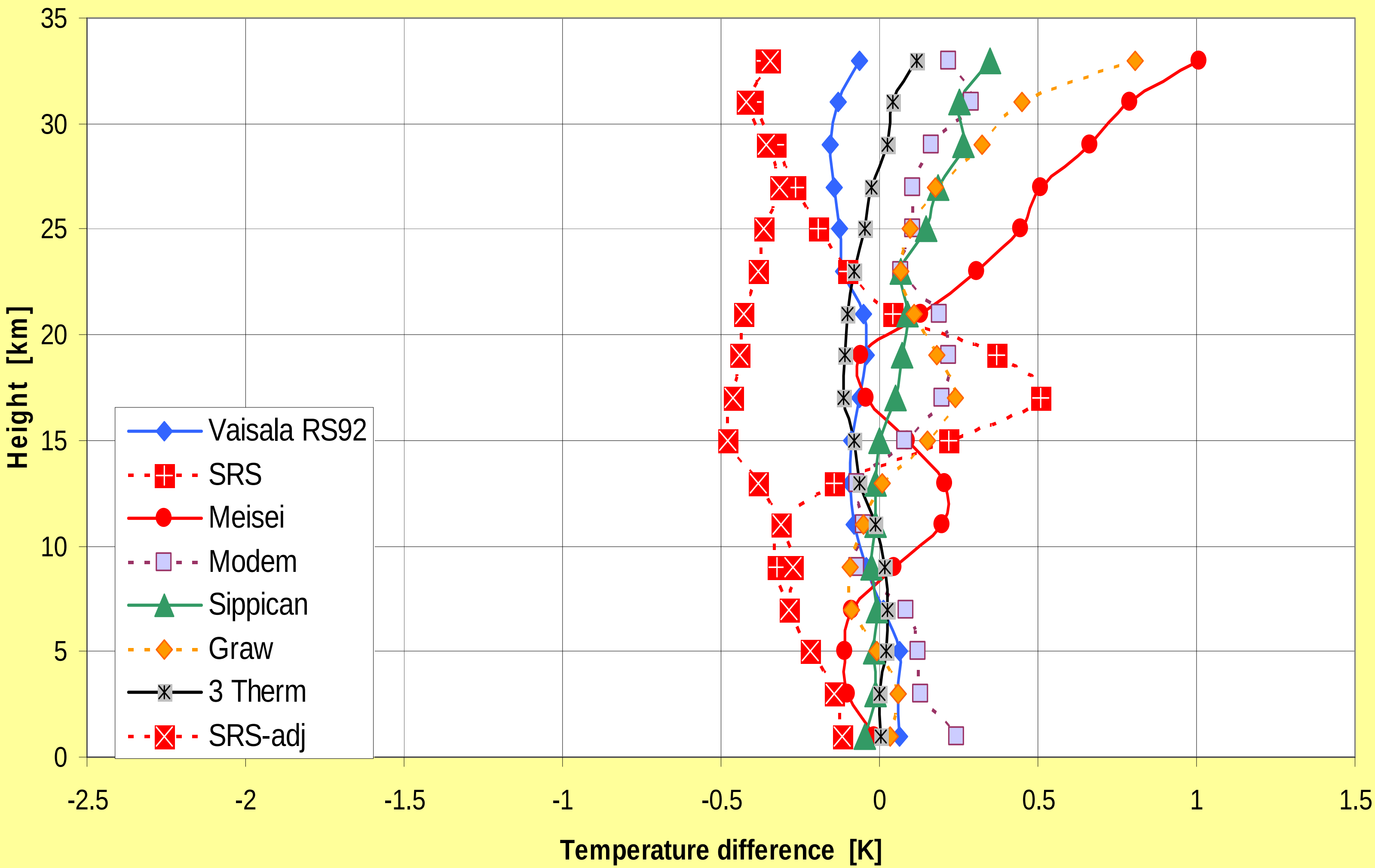
Examples of radiation corrections for daytime radiosonde temperatures ,[solar elevation 45 degrees] three types widely used between 1980 and 2000 and new Vaisala RS92



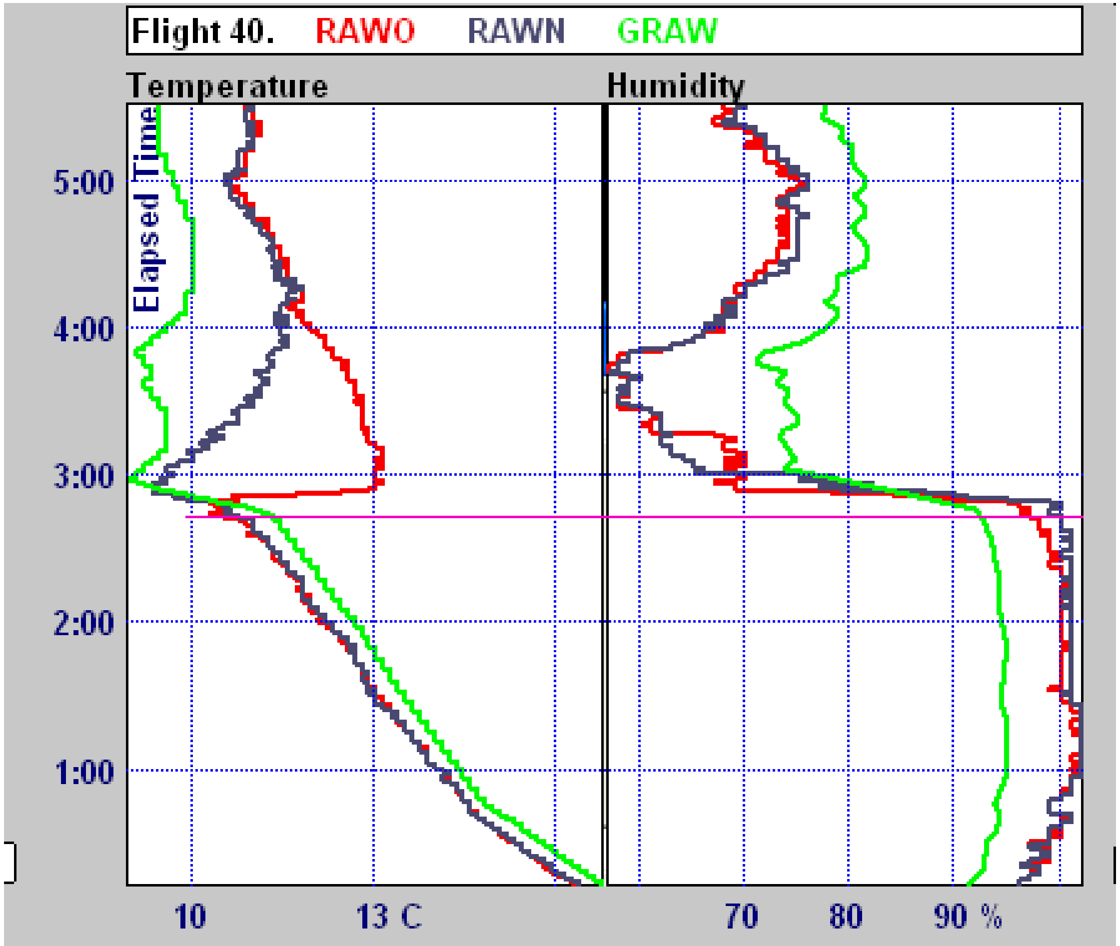
Results from WMO Radiosonde Comparison in the day .
The most reliable estimates are for Phase 4 and PREFRS, with the large difference between the two the result of the correction algorithm not representing two very different conditions.



Systematic differences in daytime temperature referenced to the nighttime reference using 3 thermistor measurements, WMO High Quality Radiosonde Comparison Test, Mauritius, 2005



Error in profiles after emerging from cloud where sensors have become wet. The wet temperature cools by evaporation in the dry air. This error is rare on Vaisala temperature sensors since they have water repellent coating.



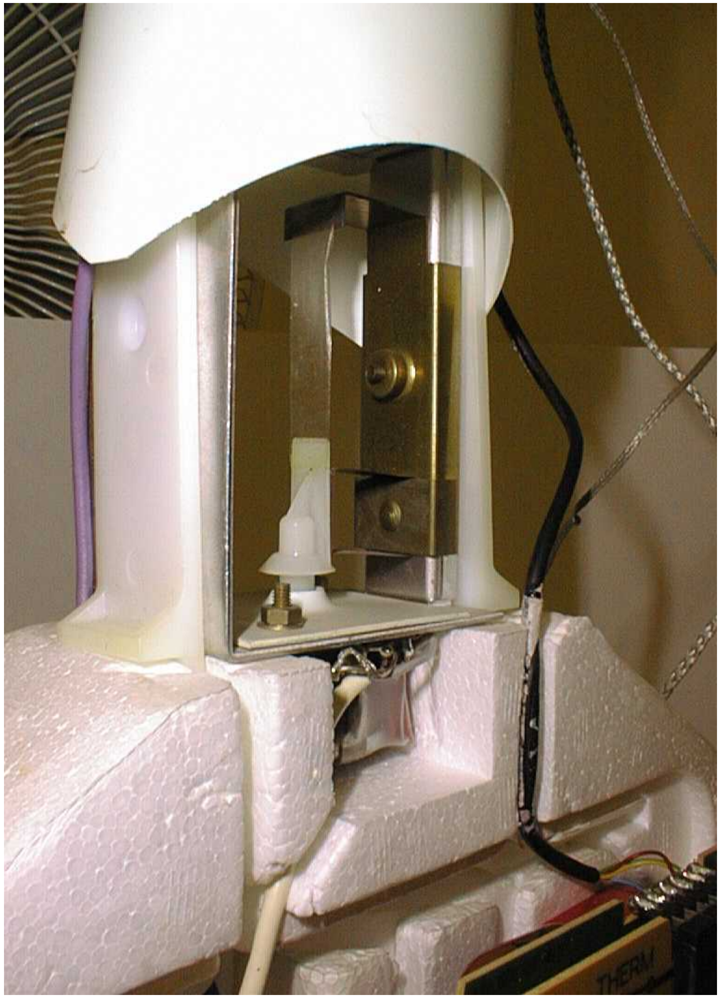
Pink line,
estimated top of cloud

Simultaneous measurements from three radiosondes,
two very similar in design [Vaisala RS92RAWO and RAW N] and from Graw

Relative humidity sensors

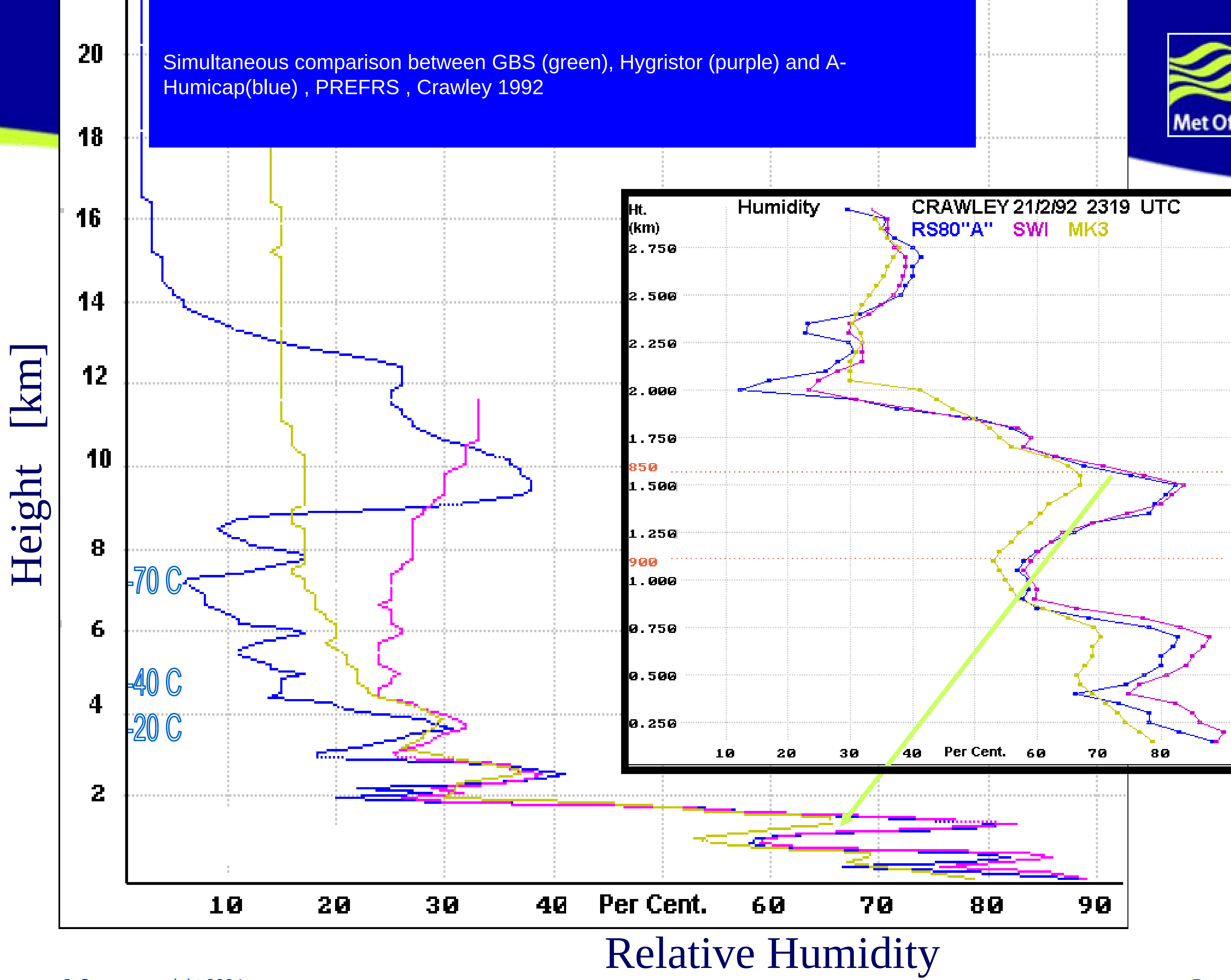
- Old type sensor typified by goldbeater’s skin which measured heights of hydrolapse reasonably well, but did not quantify the high and low values of relative humidity accurately.

Gold-beater's Skin

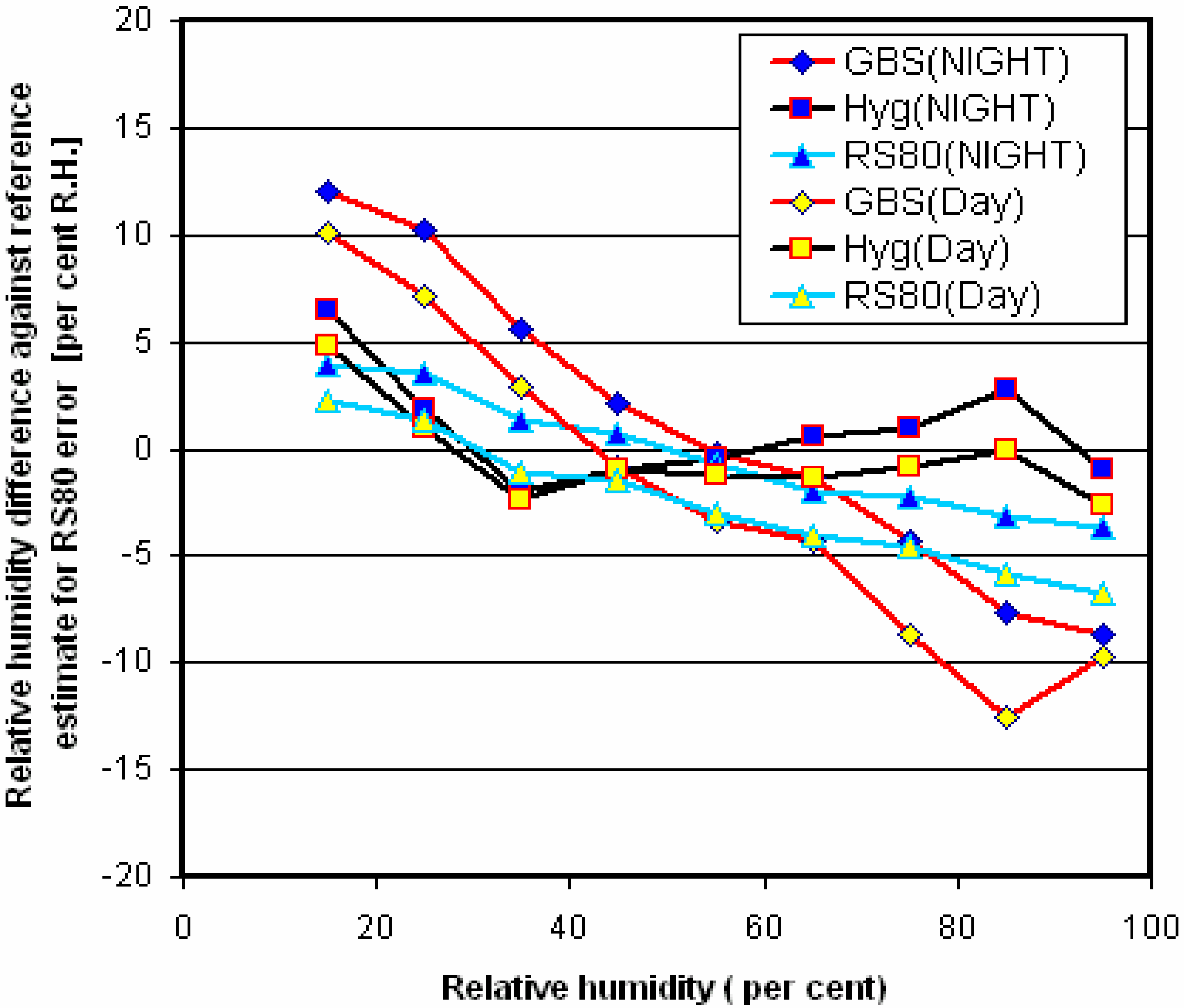


- (beef peritoneum) changes length by 5 to 7% for a change in humidity from 0 to 100%.
- Has a thickness of 0.03 mm.
- Speed of response is complex with significant hysteresis. Avoiding biases in measurements at low and high humidity is difficult.
- Systematic errors are large at high and low humidity, especially at temperatures lower than -20°C

Simultaneous comparison between GBS (green), Hygristor (purple) and A-Humicap(blue) , PREFRS , Crawley 1992



Estimated R.H. errors for temperatures between 15 and 0 °C from all WMO Radiosonde Comparisons +PREFRS , with flights through low cloud excluded



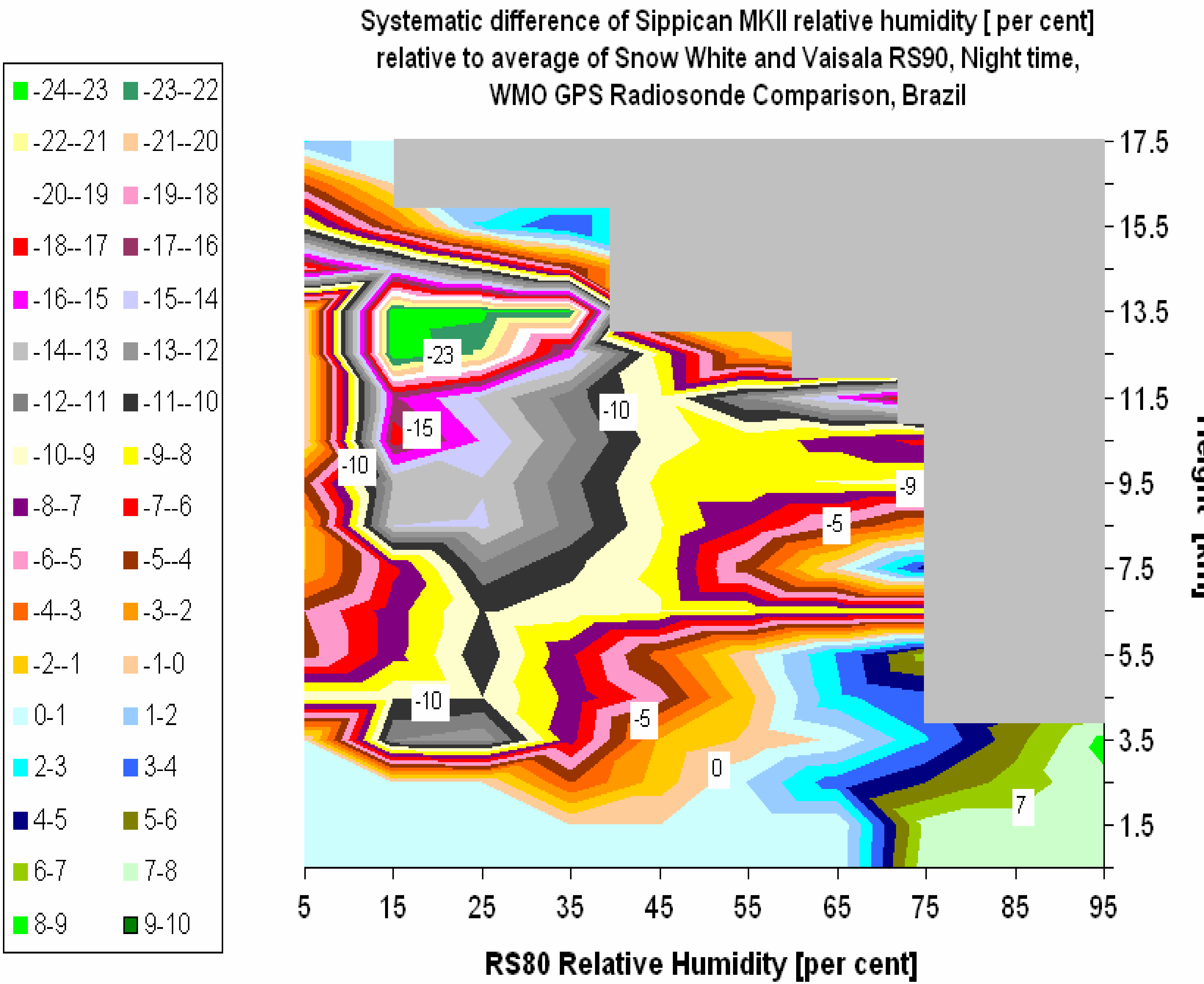
Flights that have passed through low cloud, have been excluded because the hygristors often changed calibration in cloud [low bias], and the RS80 often became contaminated [high bias]. This plot is intended to identify other basic calibration problems

Carbon Hygristor Humidity Sensor

- A polystyrene strip is coated with a thin hygroscopic film containing carbon particles.
- Electrodes are coated along each side of the sensor.
- Changes to the ambient relative humidity lead to dimensional changes in the hygroscopic film such that the resistance increases rapidly at high humidity, as the carbon particles move apart at high humidity

Carbon Hygristor Humidity Sensor

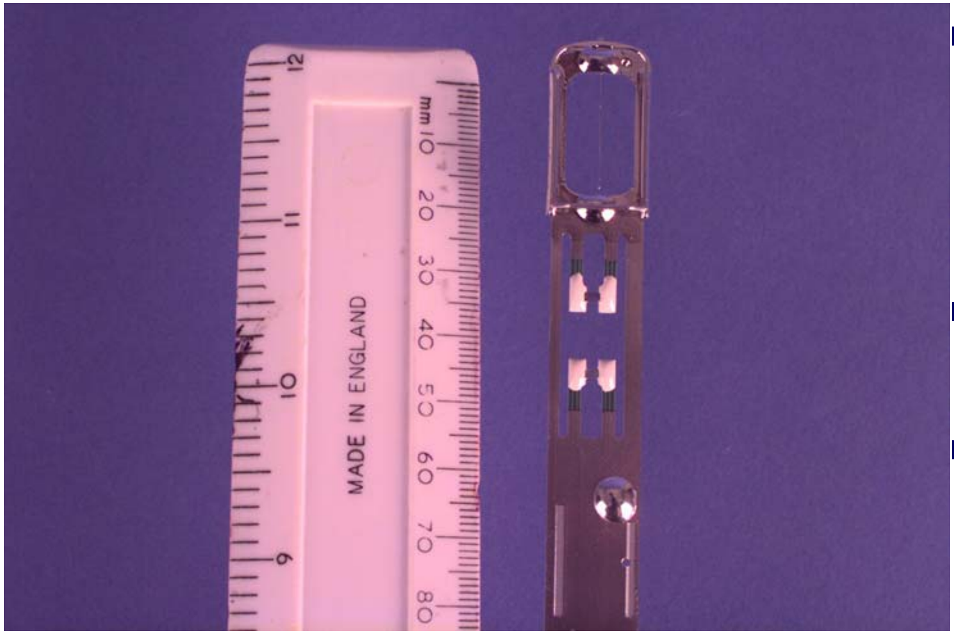
- The resistance at 90% RH is about 100 times as large as the resistance at 30% RH.
- Sensors are normally mounted in a duct to minimise the influence of precipitation wash and to prevent direct solar heating of the sensor.
- The sensor has problems with reproducibility at low humidity and may not be stable if kept for a few hours at high humidity.
- The sensor does not always work reliably at temperatures much lower than -40°C and also at low relative humidity, see next slide.
- Large sensors are likely to have significant temperature lag relative to actual temperature, leading to some negative bias in the measurements.



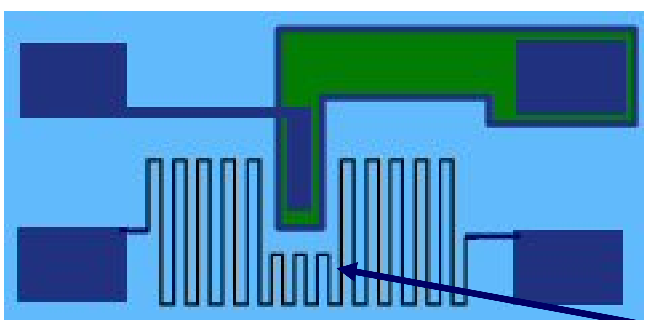
Systematic difference of Sippican MKII relative humidity [per cent]
relative to average of Snow White and Vaisala RS90, Night time,
WMO GPS Radiosonde Comparison, Brazil
-24--23
-23--22
-22--21
-21--20
-20--19
-19--18
-18--17
-17--16
-16--15
-15--14
-14--13
-13--12
-12--11
-11--10
-10--9
-9--8
-8--7
-7--6
-6--5
-5--4
-4--3
-3--2
-2--1
-1-0
0-1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
-23
-10
-15
-10
-9
-5
-10
-5
0
7
17.5
15.5
13.5
11.5
9.5
7.5
5.5
3.5
1.5
Height [km]
5
15
25
35
45
55
65
75
85
95
RS80 Relative Humidity [per cent]

Vaisala RS92 Humidity Sensors

Met Office



- The latest Vaisala sensors are uncapped and are alternately pulse heated to remove contamination.
- Each sensor incorporates a small heating resistor.
- This heating is used to drive off chemical contamination during the ground check.

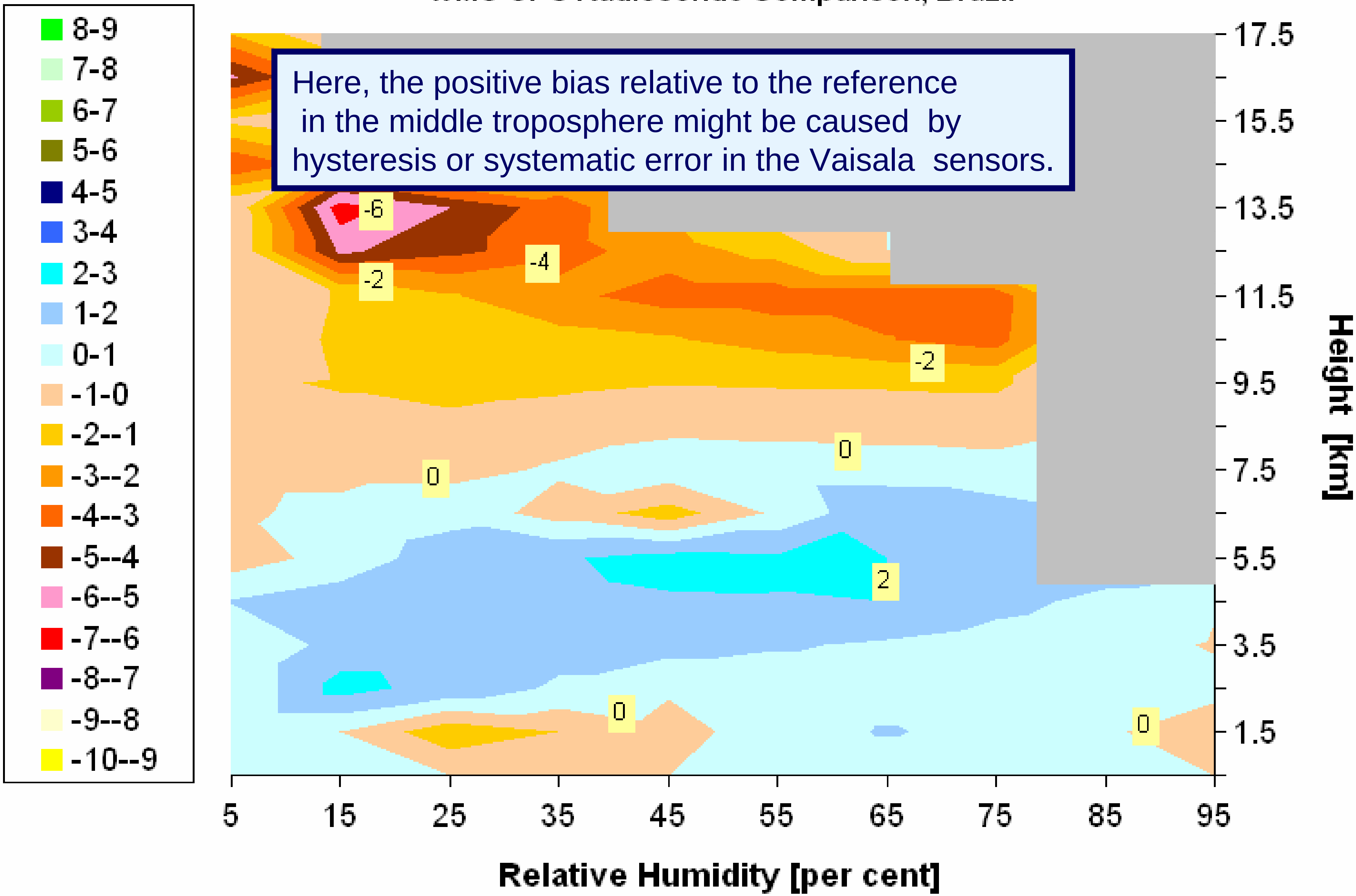


1.5 mm

Heating resistor

4 mm

Systematic difference of Vaisala RS90 relative humdity [per cent] relative to average of Snow White and Vaisala RS90, Night time, WMO GPS Radiosonde Comparison, Brazil



Questions & Answers