Session 3: Instruments, Platforms and Deployment Options

15:15-17:00
Session 3: Instruments, Platforms and Deployment Options
Co-chairs: Junhong Wang and Mike Hardesty

Talks (all 30 minutes)
• Reference Radiosonde Options, *Junhong Wang NCAR*
• Measurements of Temperature, Water Vapor, Clouds, and Winds Derived from Ground-Based Remote Sensors; Measurements of the Surface Radiation Balance, *Jim Liljgren ANL*
• GPS Atmospheric Sensing, *Chris Rocken NCAR*
• GCOS reference UA observation network: LUAMI intercomparison campaign, *Franz H. Berger, DWD*

Tuesday 23rd May
8:30-10:00 Special Discussion Session: Emerging Instrument Options from Manufacturers
10:00-10:30 Coffee break
10:30-12:00 Session 3 continued
Reference Radiosonde System Options for Climate Studies: Introduction for discussions

Junhong (June) Wang
NCAR/EOL/T"MES

Co-authors: Frank Schmidlin, Holger Voemel, Mark Paige, Joe Focundo, Jim Fitzgibbon …
Outlines

- Goals
- Requirements
- Sensor options (T, WV, P, wind and other variables)
- Integration
- Challenges to make a reference system
- Challenges to maintain long-term stability
- Summary
Goals of Upper-Air Reference Network

- Provide long-term, high-quality climate records
- Serve to constrain and calibrate data from more spatially-comprehensive global observing systems (inc. satellites)
- Measure a larger suite of co-related climate variables than can be provided as benchmark observations

From Seidel and Thorne’s talk
## Requirements

<table>
<thead>
<tr>
<th></th>
<th>Temperature</th>
<th>Water Vapor</th>
<th>Pressure</th>
<th>Vector Wind</th>
<th>Ozone</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Priority (1-4)</strong></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><strong>Measurement Range</strong></td>
<td>100-350 K</td>
<td>0.1 ppm to 55 g/kg</td>
<td>1 to 1100 hPa</td>
<td>0 – 300 m/s</td>
<td>0.005-20 ppmV</td>
</tr>
<tr>
<td><strong>Vertical Range</strong></td>
<td>0 km to stratopause</td>
<td>0 to ~30 km</td>
<td>0 km to stratopause</td>
<td>0 km to stratopause</td>
<td>Surface to 100 km</td>
</tr>
<tr>
<td><strong>Vertical Resolution</strong></td>
<td>0.1 km (surface to ~30 km)</td>
<td>0.05 km (surface to 5 km)</td>
<td>0.1 km (5 to ~30 km)</td>
<td>0.05 km in troposphere</td>
<td>0.5 km in stratosphere</td>
</tr>
<tr>
<td><strong>Precision</strong></td>
<td>0.2 K</td>
<td>0.1 g/kg in lower troposphere</td>
<td>0.001 g/kg in upper troposphere</td>
<td>0.1 hPa</td>
<td>0.5 m/s in troposphere</td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td>0.1 K in troposphere</td>
<td>0.5 g/kg in lower troposphere</td>
<td>0.005 g/kg in upper troposphere</td>
<td>0.1 hPa</td>
<td>1.0 m/s in stratosphere</td>
</tr>
<tr>
<td><strong>Long-Term Stability</strong></td>
<td>0.05 K(^1)</td>
<td>1(^{11})%</td>
<td>0.1 hPa</td>
<td>0.5 m/s in troposphere</td>
<td>0.2% total column</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.0 m/s(^1)</td>
<td>0.6% stratosphere</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1% troposphere</td>
</tr>
<tr>
<td>Sonde</td>
<td>Sensor</td>
<td>Measurement Range (°C)</td>
<td>Precision Resolution (°C)</td>
<td>Accuracy (°C)</td>
<td>Long-Term Stability (°C/decade)</td>
</tr>
<tr>
<td>---------------</td>
<td>-------------------------</td>
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<td>----------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td><strong>Requirements</strong></td>
<td></td>
<td>-170 ~ 77</td>
<td>0.2</td>
<td>0.1/0.2 in TR/ST</td>
<td>0.05</td>
</tr>
<tr>
<td>NASA ATM</td>
<td>3-thermistor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.2/0.2-0.3 in TR/ST</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sippican multi-thermistor</td>
<td>3 aluminized chips</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vaisala RS92</td>
<td>Aluminized capacitance</td>
<td>-90 ~ 60</td>
<td>0.2/0.3/0.5 (1080-100/100-20/20-3 hPa)</td>
<td>0.1</td>
<td>0.5 (total)</td>
</tr>
<tr>
<td>Sippican LMS-5</td>
<td>Aluminized chip thermistor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graw DFM-97</td>
<td>Aluminized bead thermistor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meisei RS-01G</td>
<td>Aluminized bead thermistor</td>
<td></td>
<td></td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>Meteolabor SRSD-C34</td>
<td>Thermocouple</td>
<td>-100 ~ 60</td>
<td>?</td>
<td>0.01</td>
<td>0.1</td>
</tr>
<tr>
<td>Modem M2K2</td>
<td>White bead thermistor</td>
<td>-90 ~ 55</td>
<td>?</td>
<td>0.1</td>
<td>0.5</td>
</tr>
</tbody>
</table>
1. Daytime radiation error is the most significant one.
2. Errors vary with locations.

From Frank Schmidlin
Radiation errors

Option #1: Multi-thermistor Technology

- Simultaneously solving multiple heat balance equations;
- Each with different emissivity and absorptivity values;
- Conduction and thermal lag error correction are included;
- Knowledge of the environmental radiative background is not necessary.

**Optional #2: Better radiation corrections**

- Radiation sensors on the sonde
- Calculating radiation flux profiles with observed cloud, aerosol and other parameters

\[ mC\left(\frac{dT}{dt}\right) = q_{\text{abs}} - q_{\text{emit}} + q_{\text{conv}} + q_{\text{elec}} + q_{\text{cond}} \]

Luers (1990)
### Water Vapor

<table>
<thead>
<tr>
<th>Measurement Range</th>
<th>Precision</th>
<th>Accuracy</th>
<th>Long-Term Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 ppm to 55 g/kg</td>
<td>0.1/0.001 g/kg in LT/UT</td>
<td>0.5/0.005 g/kg in LT/UT</td>
<td>1%/decade</td>
</tr>
<tr>
<td></td>
<td>0.1 ppm in ST</td>
<td>0.1 ppm in ST</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Device</th>
<th>Claimed accuracy</th>
<th>Calibration</th>
<th>Limitations</th>
<th>Dynamic range</th>
<th>Histor y</th>
<th>Cost</th>
<th>Ease of use</th>
<th>Engineering</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFH</td>
<td>0.5°C DP/FP 4-9%</td>
<td>++</td>
<td>No &quot;wet&quot; clouds</td>
<td>++</td>
<td>+</td>
<td>- (o)</td>
<td>o</td>
<td>research / small series</td>
</tr>
<tr>
<td>Snow White</td>
<td>0.1°C DP/FP</td>
<td>+</td>
<td>Some clouds RH &gt; 3-6%</td>
<td>o</td>
<td>+</td>
<td>o</td>
<td>++</td>
<td>production small series</td>
</tr>
<tr>
<td>Lyman-alpha (FLASH)</td>
<td>9%</td>
<td>+</td>
<td>Night time only Descent only No ST</td>
<td>+</td>
<td>o</td>
<td>--</td>
<td>+</td>
<td>research / small series</td>
</tr>
<tr>
<td>TDL (MayComm)</td>
<td>5% 0.5 ppmv</td>
<td>o</td>
<td>Discontinuation of laser used</td>
<td>+</td>
<td>-</td>
<td>--</td>
<td>(++)</td>
<td>Proof of concept</td>
</tr>
<tr>
<td>TDL (SW)</td>
<td>2%</td>
<td>o</td>
<td>Impacts of cloud droplets</td>
<td>+</td>
<td>--</td>
<td>--</td>
<td>?</td>
<td>No field testing</td>
</tr>
<tr>
<td>Polymer (Vaisala RS92)</td>
<td>1% RH</td>
<td>-</td>
<td>No ST Large radiation error Chemical contamination Hard to trace sensor/calibration changes</td>
<td>-</td>
<td>+</td>
<td>++</td>
<td>+ (+)</td>
<td>Large scale production</td>
</tr>
</tbody>
</table>

Water Vapor Measurement Range Precision Accuracy Long-Term Stability

- **CFH**
  - Claimed accuracy: 0.5°C DP/FP 4-9%
  - Calibration: ++
  - Limitations: No "wet" clouds
  - Dynamic range: ++
  - History: +
  - Cost: - (o)
  - Ease of use: o
  - Engineering: research / small series

- **Snow White**
  - Claimed accuracy: 0.1°C DP/FP
  - Calibration: +
  - Limitations: Some clouds RH > 3-6% No ST
  - Dynamic range: o
  - History: +
  - Cost: o
  - Ease of use: ++
  - Engineering: production small series

- **Lyman-alpha (FLASH)**
  - Claimed accuracy: 9%
  - Calibration: +
  - Limitations: Night time only Descent only No LT
  - Dynamic range: +
  - History: o
  - Cost: --
  - Ease of use: +
  - Engineering: research / small series

- **TDL (MayComm)**
  - Claimed accuracy: 5% 0.5 ppmv
  - Calibration: o
  - Limitations: Discontinuation of laser used
  - Dynamic range: +
  - History: -
  - Cost: --
  - Ease of use: (++)
  - Engineering: Proof of concept

- **TDL (SW)**
  - Claimed accuracy: 2%
  - Calibration: o
  - Limitations: Impacts of cloud droplets
  - Dynamic range: +
  - History: --
  - Cost: --
  - Ease of use: ?
  - Engineering: No field testing

- **Polymer (Vaisala RS92)**
  - Claimed accuracy: 1% RH
  - Calibration: -
  - Limitations: No ST Large radiation error Chemical contamination Hard to trace sensor/calibration changes
  - Dynamic range: -
  - History: +
  - Cost: ++
  - Ease of use: + (;++)
  - Engineering: Large scale production
940 nm Balloon Borne Hygrometer  

**Lab Comparison**

- Accuracy 2.5%, Precision 1.0%
- Noise levels (1 sec)
  - Altitude
    - Low: 2 mb (-72 C)
    - High: 0.9 mb (-77 C)
- 500 – 750 mW power consumption
- 230 g weight (with batteries)

Improvements have been subsequently made in electronics and lasers

From Mark Paige
<table>
<thead>
<tr>
<th>Sonde</th>
<th>Sensor</th>
<th>Measurement Range (hPa)</th>
<th>Precision (hPa)</th>
<th>Accuracy (hPa)</th>
<th>Long-Term Stability (hPa/decade)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirements</td>
<td>1-1100</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1?</td>
<td>0.1</td>
</tr>
<tr>
<td>Vaisala RS92</td>
<td>Capacitive silicon</td>
<td>3-1080</td>
<td>0.5/0.3 in TR/ST</td>
<td>1.5/0.6 (total)</td>
<td></td>
</tr>
<tr>
<td>Graw DFM-97</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meisei RS-01G</td>
<td>Aneroid capsule</td>
<td>5-1040</td>
<td>?</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Meteolabor SRSD-C34</td>
<td>Hypsometer</td>
<td>5-1100</td>
<td></td>
<td>0.2 (unstable)</td>
<td></td>
</tr>
<tr>
<td>iMet-1</td>
<td>Piezoresistive</td>
<td>2-1070</td>
<td></td>
<td>1.8/0.5 (&gt;/-&lt; 400 hPa)</td>
<td></td>
</tr>
</tbody>
</table>

Q:

- Do we need a pressure sensor?
- Are precision and accuracy requirement set too high for troposphere?
Systematic and random errors in pressure (WMO 2005)

Requirements:
1 hPa in Troposphere
0.2 hPa in Stratosphere
1. < 5% missing GPS data

2. GPS-geopotential height is more accurate that calculated from pressure sensors for Z > 16 km, but similar for Z < 16 km.

3. Random error for GPH_GPS is ≤ 15 m and does not vary with height, but that for GPH_P increases with heights.

4. The conversion from geometric to geopotential heights is essential for the comparison.

5. “GPS heights are suitable to replace geopotential from pressure sensors at all heights, i.e. a pressure sensor is no longer a necessity for a best quality radiosonde. The reproducibility of the GPS geopotential heights at 32 km was an order of magnitude better than the reproducibility of the heights from the best pressure sensors.”
<table>
<thead>
<tr>
<th>Sonde</th>
<th>Measurement Range (m/s)</th>
<th>Precision (m/s)</th>
<th>Accuracy (m/s)</th>
<th>Long-Term Stability (m/s/decade)</th>
<th>Position accuracy (m horizontal/vertical)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Requirements</strong></td>
<td>0-300</td>
<td>0.5/1.0 in TR/ST</td>
<td>1.0</td>
<td>0.5/1.0 in TR/ST</td>
<td></td>
</tr>
<tr>
<td>Vaisala RS92</td>
<td></td>
<td></td>
<td>0.2</td>
<td></td>
<td>10/20</td>
</tr>
<tr>
<td>Sippican LMS-5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>Graw DFM-97</td>
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<tr>
<td>Meisei RS-01G</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meteolabor SRSD-C34</td>
<td></td>
<td>0.12</td>
<td></td>
<td>2.5/5</td>
<td></td>
</tr>
<tr>
<td>Modem M2K2</td>
<td></td>
<td></td>
<td>0.15</td>
<td></td>
<td>10/1</td>
</tr>
<tr>
<td>iMet-1</td>
<td></td>
<td></td>
<td>1.0</td>
<td></td>
<td>5/15</td>
</tr>
<tr>
<td>WMO 2005</td>
<td></td>
<td>0.05/0.1 in TR/ST</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Other special radiosondes

**Electricity:**
Electric field probe

**Radioactivity sonde:**
B and \(\gamma\) radioactivity

**Ozonesonde:**
ozone profiles

**In-cloud measurements:**
changes in charge, aerosols

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http://www.atd.ucar.edu/homes/junhong/MT11B_radiosondes.pdf from UK Met office
Integration as a system

- Smart and careful design to minimize extra errors,
- High performance and multi-channel transmitter,
- Digital and reliable data transmission and reception,
- Flexible infrastructure to host additional sensors
- Mobility and portability
- ???
Challenges of making a sonde as a reference

- Select best sensors
  (laboratory standards, target specifications, reliable calibration)

- Take extraordinary procedures to produce the best data
  (ventilation, radiation, ...)

- Calibrate to NIST (in-house/in-field) and keep a detailed metadata

- Inter-compare multiple sensors and systems
  (redundancy, pre-launch check, “Consensus ref. concept”...)

- Real-time data quality monitoring and careful post data QC

- Effective communications among different stakeholders
  (operational center, data center, manufactures, data users ...)
Comparisons of prelaunch radiosonde and surface data (both in field and post-processing)

**Compare Radiosonde Data to Surface Data System**

<table>
<thead>
<tr>
<th>Surface Data System Values</th>
<th>Sonde Values</th>
<th>Sonde Sensor Offsets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure (mb) 833.2</td>
<td>833.8</td>
<td>-0.6 mb</td>
</tr>
<tr>
<td>Air Temp (°C) 18.6</td>
<td>18.4</td>
<td>0.2 °C</td>
</tr>
<tr>
<td>Humidity (%) 34.4</td>
<td>31.5</td>
<td>2.9 %</td>
</tr>
</tbody>
</table>

Time of Last Surface Data Measurement: 21:01:15

**INDOEX sagar (raw)**
Feb-Apr 1999

Compare the sonde sensor values above to the Surface Data System values.

Acceptable Sonde Sensor Offset Limits:
- Pressure 5 mb
- Air Temp 2 °C
- Humidity 10 %

Click: **Continue** if Sonde Offset values are reasonable.

Click: **Bad Sonde!** if the values indicate a bad sensor. This choice will return you to the 'Prepare Radiosonde' display.

[Buttons: Bad Sonde!, Continue]

NCAR
Comparison of GPS- and radiosonde-PW at 102 stations

Comparisons of PW
(IGRA-GPS 2003/2004 102 stations)

Station Numbers

Vaisala

MRZ/Mars

IM-MK3
Challenges to maintain long-term stability

- Deliver the best quality data
- Sustain consistence in operational procedures
- Maintain complete metadata
- Ongoing data QC and analysis to identify and fix problems
- Preserve raw data and other independent/redundant data for future reprocessing and reanalysis
Generic Approach for Studying Sounding Characteristics, Biases and Impacts

Identifying

Understanding

Developing correction schemes

Applying to climate, field and operational data

Applying to operational network and field projects

Engineers

Manufactures

Hardware/ Sensor improvements
Summary

- **Temperature**: multi-thermistor or better radiation corrections
- **Water vapor**: TDL, dew/frost-point hygrometer, Polymer
- **Pressure/height**: any or no pressure sensor
- **GPS wind**: any (cost and size)
- **Other variables**: ozone and what else?
- **Integration**: sensor module design, transmitter, mobility, portability …
- **“Reference”**: best sensors, extraordinary procedures, calibration, inter-comparisons, real-time data quality monitoring, effective communications …
- **“Long-term stability”**: best quality, consistence, metadata, data QC and analysis, redundancy …