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[II]MES

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

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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

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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

- Long term stability
- Accuracy
- Multiple variables

From Seidel and Thorne's talk

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Requirements

	Temperature	Water Vapor	Pressure	Vector Wind	Ozone
Priority (1-4)	1	1	1	2	2
Measurement Range	100-350 K	0.1 ppm to 55 g/kg	1 to 1100 hPa	0 – 300 m/s	0.005-20 ppmV
Vertical Range	0 km to stratopause	0 to ~30 km	0 km to stratopause	0 km to stratopause	Surface to 100 km
Vertical Resolution	0.1 km (surface to ~30 km) 0.5 km (above ~30 km)	0.05 km (surface to 5 km) 0.1 km (5 to ~30 km)	0.1 hPa	0.05 km in troposphere 0.25 km in stratosphere	0.5 km in stratosphere 1 km in troposphere
Precision	0.2 K	0.1 g/kg in lower troposphere 0.001 g/kg in upper troposphere 0.1 ppm stratosphere	0.1 hPa	0.5 m/s in troposphere 1.0 m/s in stratosphere	
Accuracy	0.1 K in troposphere 0.2 K in stratosphere	0.5 g/kg in lower troposphere 0.005 g/kg in upper troposphere 0.1 ppm stratosphere	0.1 hPa	1.0 m/s[1]	3% total column 5% stratosphere 5% troposphere
Long-Term Stability ?	0.05 K[1]	[1]1%	0.1 hPa	0.5 m/s in troposphere 1.0 m/s in stratosphere	0.2% total column 0.6% stratosphere 1% troposphere

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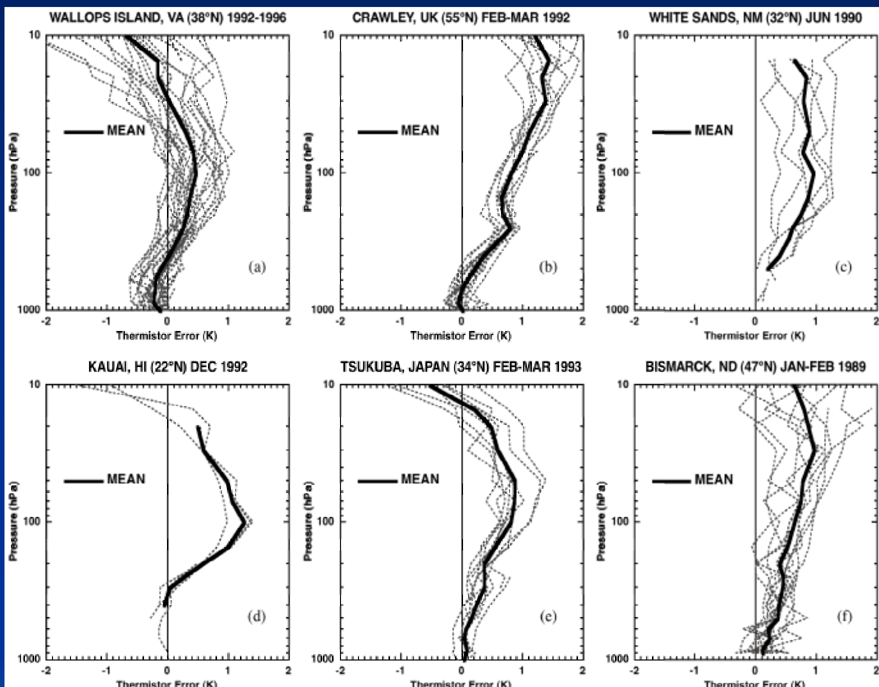
Temperature

Sonde	Sensor	Measurement Range (ºC)	Precision Resolution (ºC)	Accuracy (ºC)	Long-Term Stability (ºC/decade)
Requirements		**-170 ~ 77**	**0.2**	**0.1/0.2 in TR/ST**	**0.05**
NASA ATM	3-thermistor			0.2/0.2-0.3 in TR/ST	
Sippican multi-thermistor	3 aluminized chips				
Vaisala RS92	Aluminized capacitance	-90 ~ 60	0.2/0.3/0.5 (1080-100/100-20/20-3 hPa) **0.1**	0.5 (total)	
Sippican LMS-5	Aluminized chip thermistor				
Graw DFM-97	Aluminized bead thermistor				
Meisei RS-01G	Aluminized bead thermistor	-85 ~ 40	? ?	0.5	
Meteolabor SRSD-C34	Thermocouple	-100 ~ 60	? 0.01	0.1	
Modem M2K2	White bead thermistor	-90 ~ 55	? 0.1	0.5	

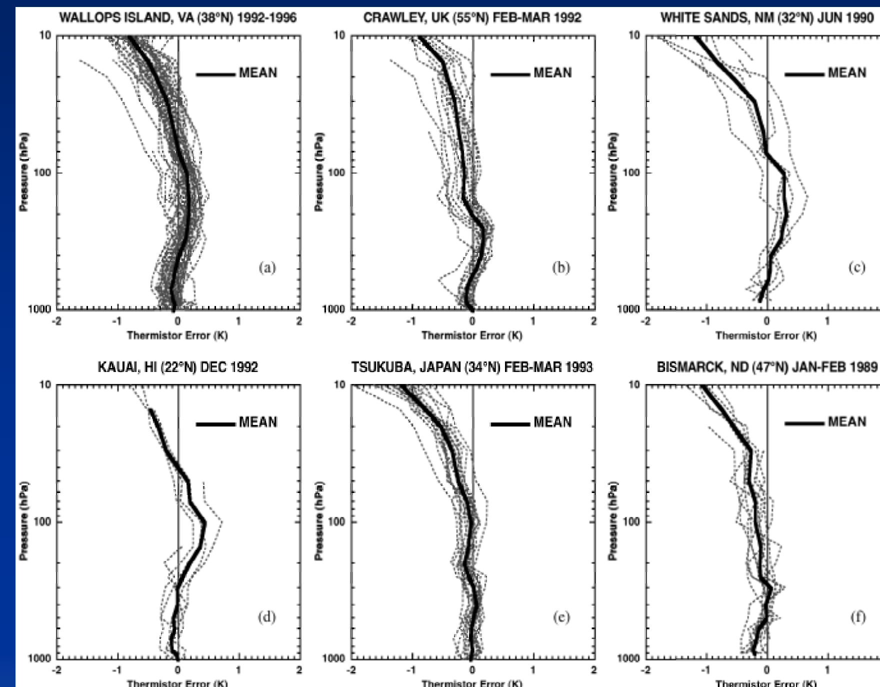
Temperature

Error of the white rod thermistor in comparison to NASA/ATM at six locations

DAYTIME



NIGHTTIME



1. **Daytime radiation error is the most significant one.**
2. **Errors vary with locations.**

From Frank Schmidlin

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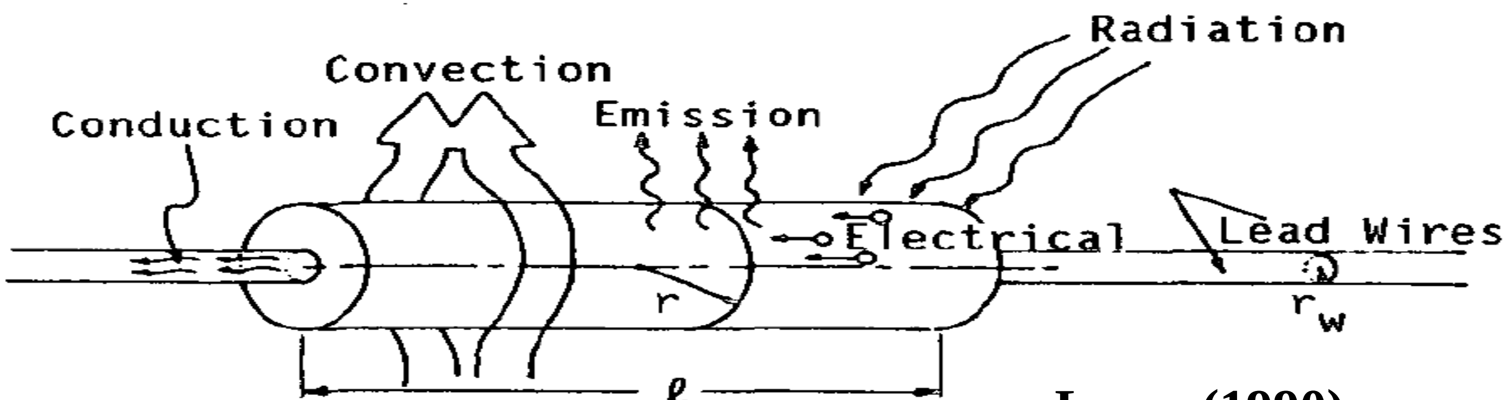
Radiation errors



Luers (1990)

FIG. 1. Thermistor geometry and heat transfer processes.

$$mC(dT/dt) = q_{abs} - q_{emit} + q_{conv} + q_{elec} + q_{cond}$$

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

Water Vapor

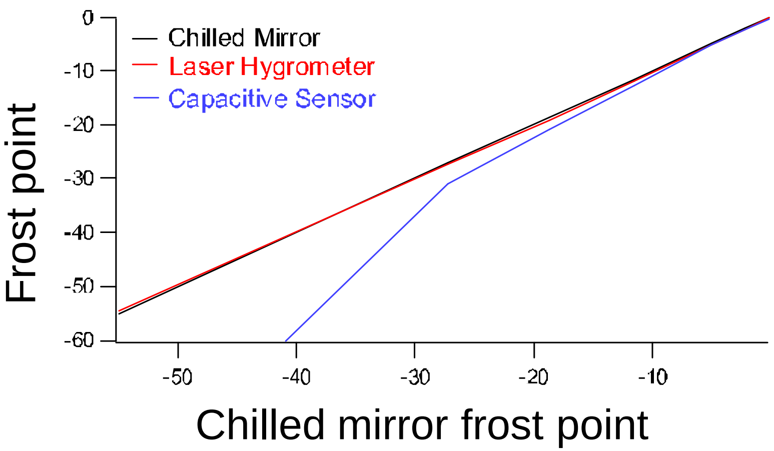
Measurement Range	Precision	Accuracy	Long-Term Stability
0.1 ppm to 55 g/kg	0.1/0.001 g/kg in LT/UT 0.1 ppm in ST	0.5/0.005 g/kg in LT/UT 0.1 ppm in ST	1%/decade

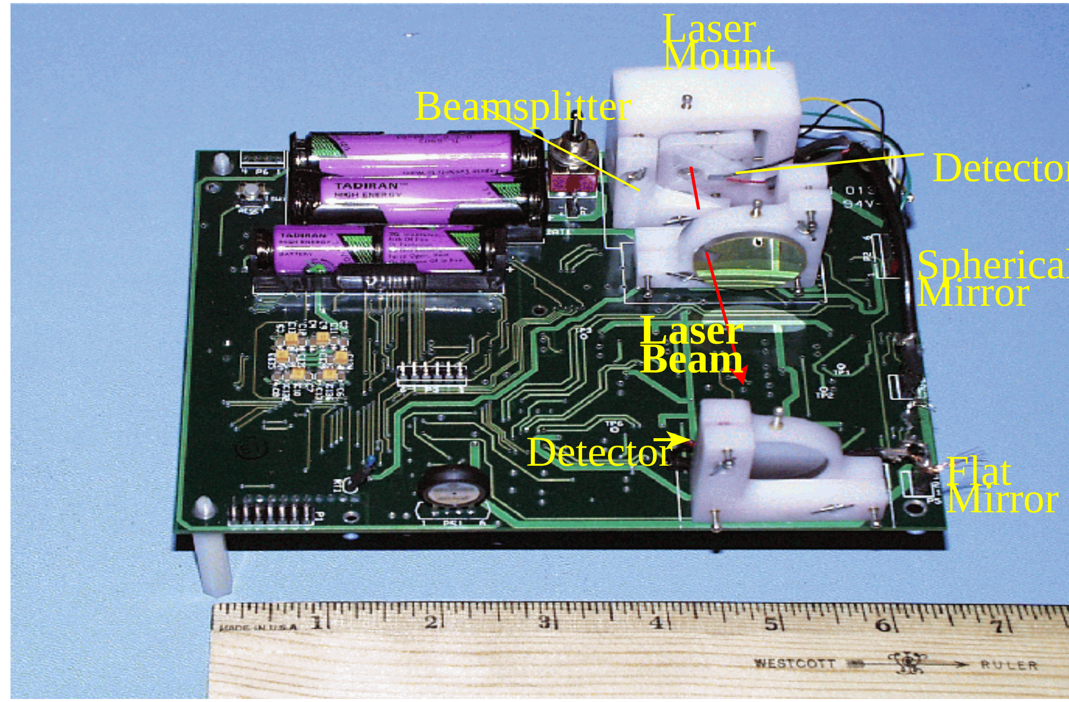
	Claimed accuracy	Calibration	Limitations	Dynamic range	History	Cost	Ease of use	Engineering
CFH	0.5°C DP/FP 4-9%	++	No "wet" clouds	++	+	- (o)	o	research / small series
Snow White	0.1°C DP/FP	+	Some clouds RH > 3-6% No ST	o	+	o	++	production small series
Lyman-alpha (FLASH)	9%	+	Night time only Descent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

940 nm Balloon Borne Hygrometer

*M.E. Paige, JOAT **22**, 1219-1224 (2005).*

Lab Comparison





- Accuracy 2.5%, Precision 1.0%
- Noise levels (1 sec)

Altitude	Low	High
	2 mb	0.9 mb
	(-72 C)	(-77 C)

- 2 m optical path
- 500 – 750 mW power consumption
- 230 g weight (with batteries)

Improvements have been subsequently made in electronics and lasers

From Mark Paige

Pressure

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

Q:

- **Do we need a pressure sensor?**
- **Are precision and accuracy requirement set too high for troposphere?**

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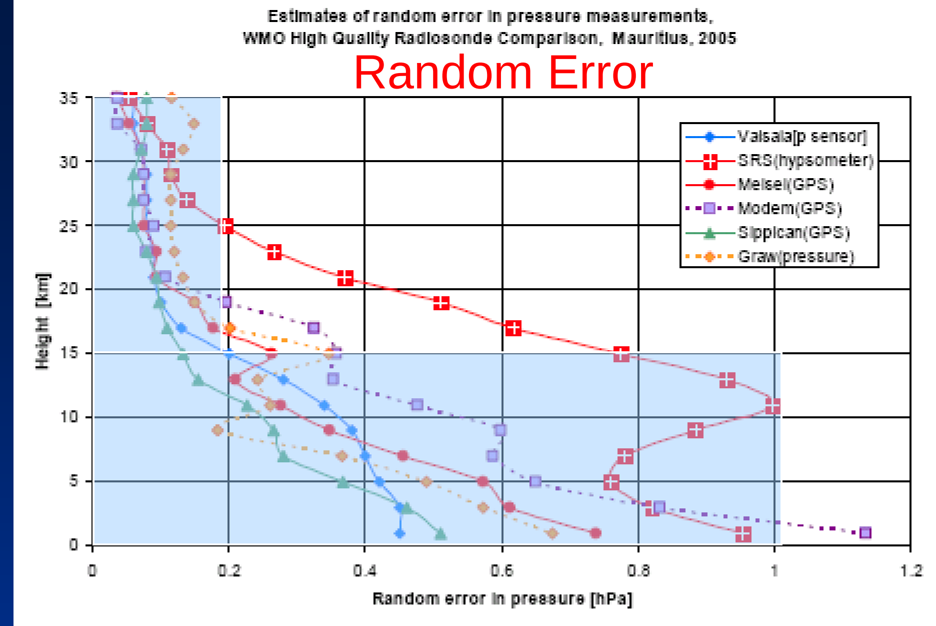
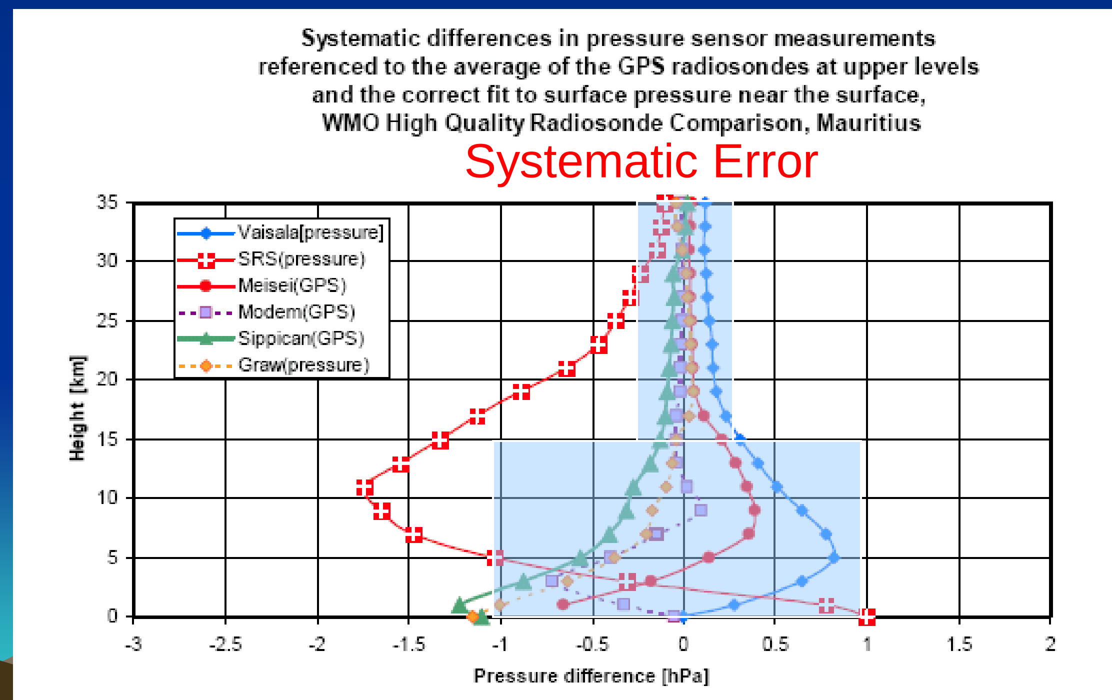
Systematic and random errors in pressure (WMO 2005)



Requirements:

1 hPa in Troposphere

0.2 hPa in Stratosphere



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Geopotential height intercomparison

(WMO radiosonde intercomparison results, Vacoas, Mauritius, 2-25 Feb. 2005)

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."

GPS wind

Sonde	Measurement Range (m/s)	Precision (m/s)	Accuracy (m/s)	Long-Term Stability (m/s/decade)	Position accuracy (m horizontal/vertical)
Requirements	**0-300**	**0.5/1.0 in TR/ST**	**1.0**	**0.5/1.0 in TR/ST**	
Vaisala RS92			0.2		10/20
Sippican LMS-5					
Graw DFM-97					
Meisei RS-01G					
Meteolabor SRSD-C34			0.12		2.5/5
Modem M2K2			0.15		10/
iMet-1			1.0		5/15
WMO 2005		0.05/0.1 in TR/ST			

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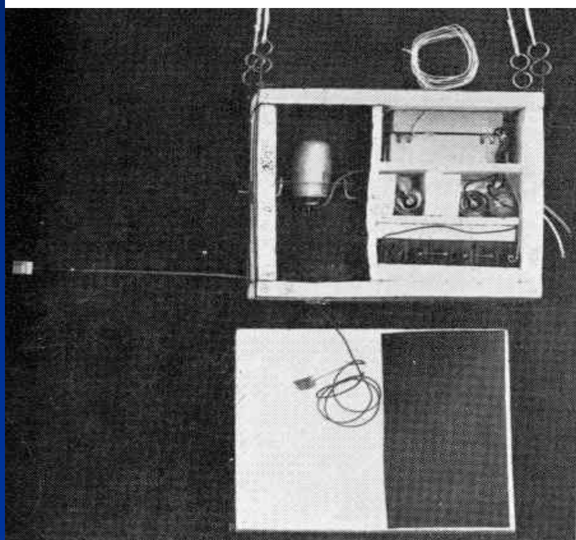
Other special radiosondes

Electricity:
Electric field probe



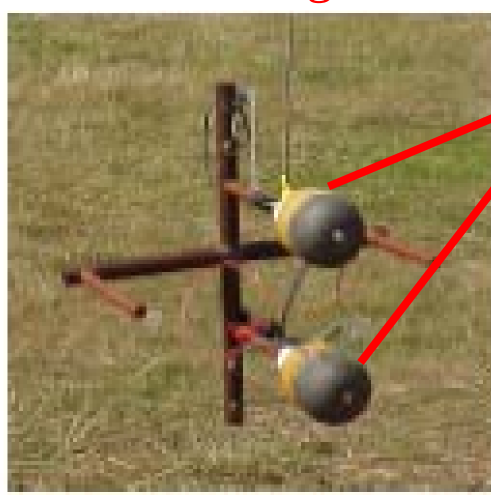
Ozonesonde:
ozone profiles

An RS80 radiosonde with ozone sensor.

Radioactivity sonde:
B and γ radioactivity

with

In-cloud measurements:
changes in charge, aerosols

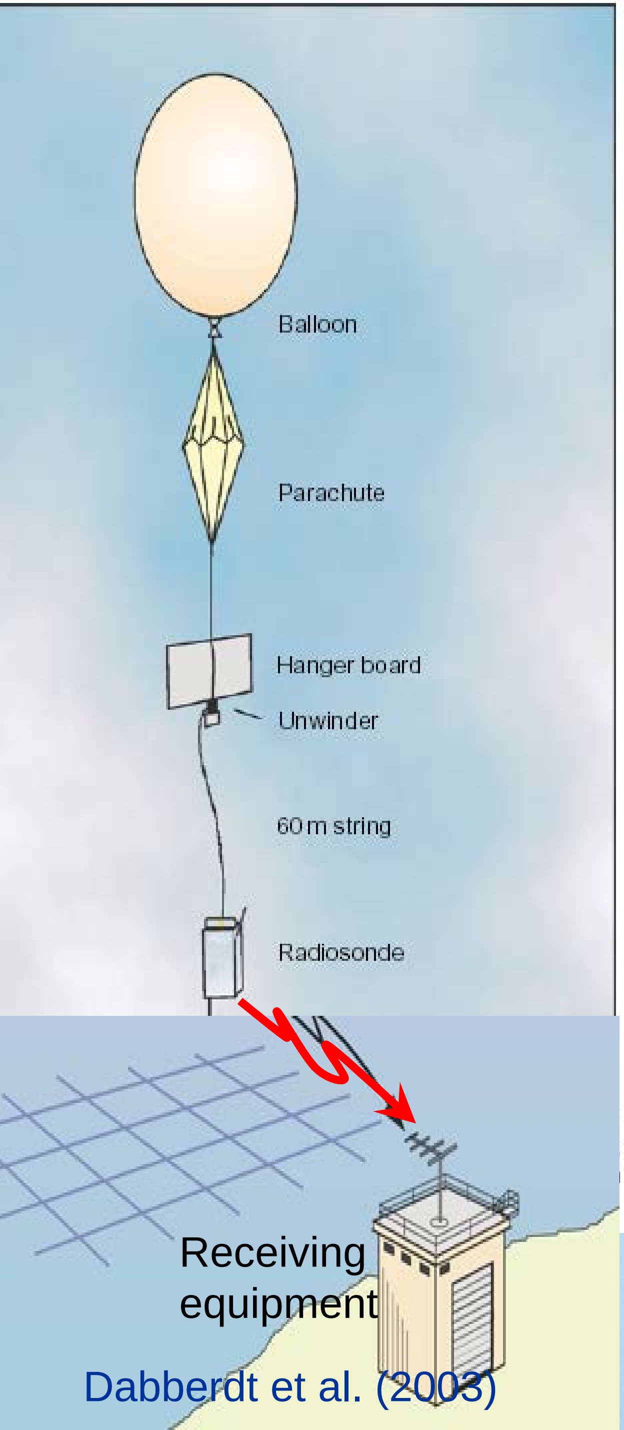


"The housing is that originally supplied to house the small plastic toy contained within a children's confectionery KinderEgg. The outer chocolate enclosure and foil coating must first be removed."

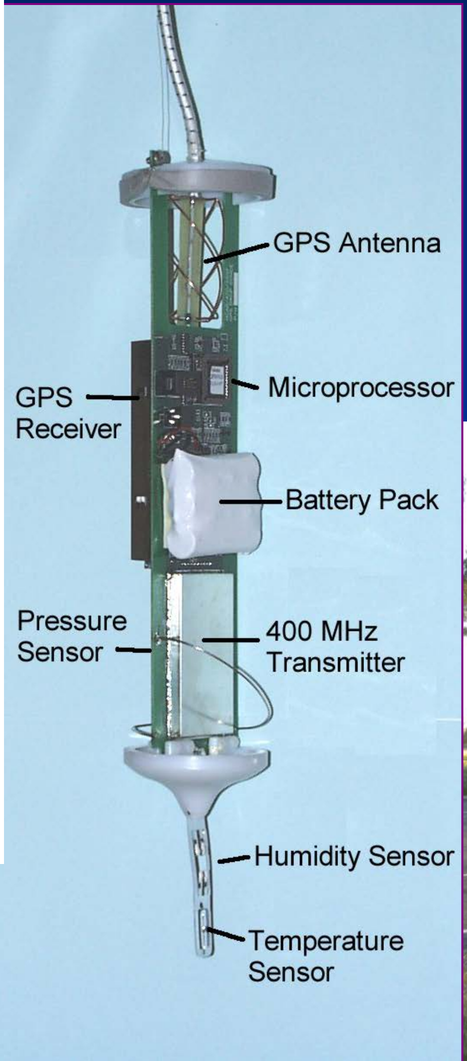
http://www.atd.ucar.edu/homes/junhong/MT11B_radiosondes.pdf from UK Met office

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
- ???



Dabberdt et al. (2003)



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 …)

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Comparisons of prelaunch radiosonde and surface data (both in field and post-processing)

Compare Radiosonde Data to Surface Data System

Surface Data System Values			Sonde Values		Sonde Sensor Offsets	
Pressure (mb)	833.2	-	833.8	=	-0.6	mb
Air Temp (C)	18.6	-	18.4	=	0.2	C
Humidity (%)	34.4	-	31.5	=	2.9	%

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

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

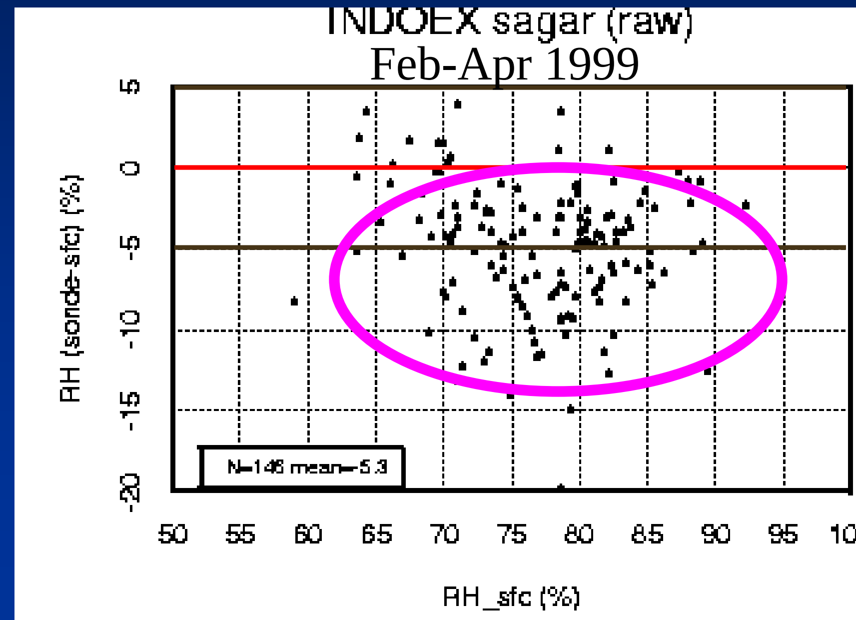
Acceptable Sonde Sensor Offset Limits:

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.

Bad Sonde! Continue



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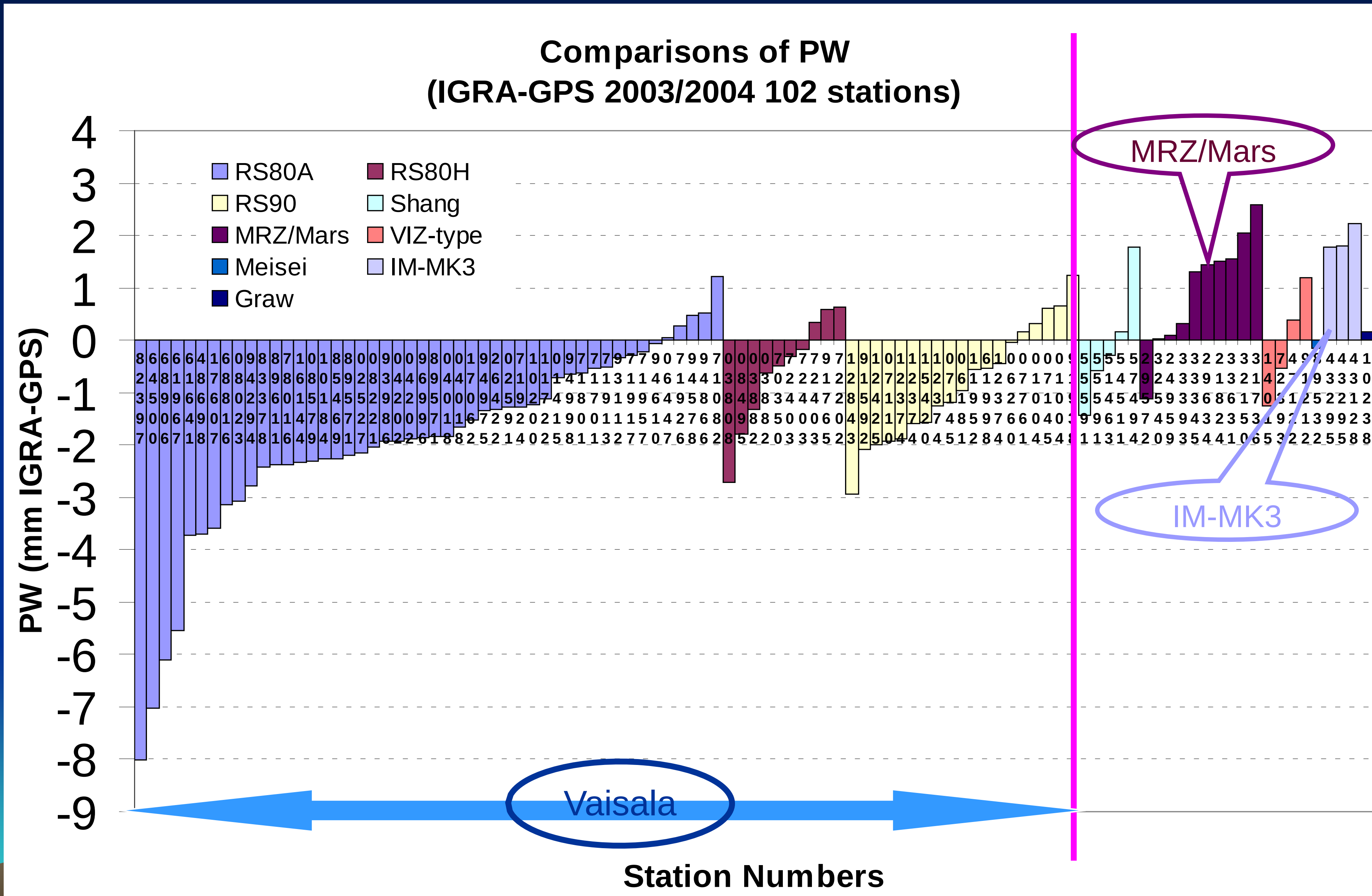
Comparison of GPS- and radiosonde-PW at 102 stations



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

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Generic Approach for Studying Sounding Characteristics, Biases and Impacts

Identifying

Understanding

Developing correction schemes

Engineers Manufactures

Hardware/ Sensor improvements

Applying to climate, field and operational data

Applying to operational network and field projects

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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 …

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