ALMA Weather Instrumentation Specification

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Description Document

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Change Record

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1 Specifications and Requirements

In the following we describe the weather measurement instrumentation required for ALMA. The choice of these instruments is based on requirements for measurement of the barometric pressure (P_s), ambient temperature (T_s), relative humidity (RH), wind speed (W_s), and wind direction (W_d) described in [Richer & Mangum(2005)]. This document also contains a specification for the instrument towers upon which a variety of devices, including these instruments, can be installed.

1.1 Environmental Requirements

The ALMA Weather Instrumentation shall operate with no degradation when experiencing any combination of the following environmental conditions[1].

— Ambient Temperature: $-20°C \leq T \leq 30°C$.
— Ambient Temperature Gradients: ±0.6°C in 10 minutes, ±1.8°C in 30 minutes.
— Wind: Speeds up to 20 m/s.
— Solar Flux: Full solar loading from any direction, with solar flux up to 1290 W/m^2.
— Dust: fine particles 1 micrometer in diameter or greater.

The general operational environment will be an outdoor location on the ALMA site at 5000m elevation.

1.2 Instrument Requirements

Table 1 lists the required accuracy for the ALMA weather instrumentation derived from [Richer & Mangum(2005)] and [Mangum(2001)]. These performance specifications stem from the ALMA Calibration Specifications and Requirements ([ALMA Dudes(2005)]) which relate mainly to pointing and amplitude calibration. The requirements on P, T, and RH are driven by the need to calculate the atmospheric refraction to better than $0.''2$. The requirements on the wind vector measurement are driven by:

— The need to correlate antenna deformation and oscillation due to wind;
— Verify wind homogeneity over the terrain around the antennas;
— Minimize measurement corruption due to downwind turbulence from adjacent antennas.

Table 1: Surface Weather Measurement Requirements

Parameter	Symbol	Required Accuracy and Range	Sampling Rate
Barometric Pressure	P_s	0.5 mb, 500–1060 mb	0.017 Hz (1 minute)
Ambient Temperature	T_s	0.1 C, -30–$+40$ C	0.017 Hz (1 minute)
Relative Humidity	RH	1.0%, 0-100%	0.017 Hz (1 minute)
Wind Speed	W_s	0.5 m/s, 0–60 m/s	1-10 Hz
Wind Direction	W_d	5 deg, 0–360 deg	1-10 Hz

NOTE: Require at least 5 of each instrument.

An additional requirement is that we sample the ambient weather conditions well-enough over the ALMA site to be able to interpolate P, T, and RH to any antenna location on the site. As we have no information regarding the variation of these weather parameters over the site, higher weight has been given to the desire to provide a larger number of measurement devices.

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[1] The conditions described represent the union of the ALMA antenna primary and secondary performance conditions.

Figure 1: Clockwise from top: PTU300 P, T, and RH sensor, HMT330MIK meteorological installation kit, and WMT50 sonic anemometer.

2 Weather Device Descriptions

In the following we list the weather instrumentation devices chosen and their performance specifications.

2.1 Barometric Pressure, Ambient Temperature, and Relative Humidity

The Vaisala PTU300 Combined Pressure, Humidity, and Temperature Transmitter has been chosen for the measurement of these three important atmospheric quantities. The techincal performace data for each sensor is listed in Table 2. A Vaisala HMT330MIK Meteorological Installation Kit will be used to mount the PTU300 on a pole or tower. Figure 1 show pictures of the PTU300 and HMT330MIK devices. For a description of the correspondence between RH, dew point temperature, and ambient (surface) temperature, see Appendix A.

Table 2: Weather Measurement Device Technical Specifications

Device	Parameter	Accuracy	Range
Class B	P_s	±0.25 mb	50–1100 hPa / −40–+60 C
PT100 RTD 1/3 Class B IEC 751	T_s	±0.20–0.3 C	−20–+40 C
HUMICAP 180C	RH	±(1.0 + 0.008 × reading) %	−20–+40 C / 0-100% RH
WMT50	W_s/W_d	max(±0.3m/s,±3%)/±3 deg	0–35 m/s / 0–360 deg

2.2 Wind Speed and Direction

For wind speed and direction measurement the WMT50 sonic anenometer has been chosen. Table 2 lists its specifications, while Figure 1 shows its mug shot. For a description of the correspondence between "sonic virtual temperature" (the quantity measured by sonic anenometers) and wind speed, see Appendix A.

3 Installation Logistics

In each of the following sections I list the installation infrastructural requirements for each component of the weather instrument installation. Figure 2 shows a sketch of a standard weather instrument installation. Table 3 lists the approximate costs for each component of a weather instrument installation.

Table 3: Weather Station Components

Component	Vendor	Model	Cost	Power Requirements
P/T/RH Sensor	Vaisala	PTU300	2760 Euro	100–240 VAC / 50-60 Hz[b]
Wind Sensor	Vaisala	WMT50	1169 Euro	5–30 VDC[c]
Computer	Arcom[a]	SBC-GX533	500 Euro	Powered from enclosure
Computer Enclosure	Arcom[a]	SBC-GX533 ICE	100 Euro	90–132/180–264 VAC or 9–36 VDC
Pole	Site IPT Specified	...	...	...
Instrument Enclosure	Hoffman	CSD16128	200 Euro	...

[a] Now EuroTech.
[b] Has own power supply module which converts input VAC to 5–30 VDC.
[c] One each for both communications and heating systems.

3.1 Locations

Locations for each weather station have been chosen based on the following criteria:

— Location (d_t):

1. $20m < d_t < 50m$ from any antenna.
2. $d_t > 100$m from any other structure.

— $\lesssim 100$ m of elevation change between stations along each arm of the ALMA array configuration

— Sufficient sampling along each arm of the ALMA array configuration to allow interpolation of (P,T,RH,W_s,W_{dir}) measurements.

Based on these criteria locations for each of 12 weather station installations have been chosen (Table 4).

3.2 Measurement Device Mount

The instrument mounting heights and locations for each of the 12 weather instrument towers should be assigned based on the following requirements:

1. 100 mm diameter pole (to interface with Vaisala HMT330MIK meteorological installation kit; see Figure 1).
2. Height (h_t): 10 m.

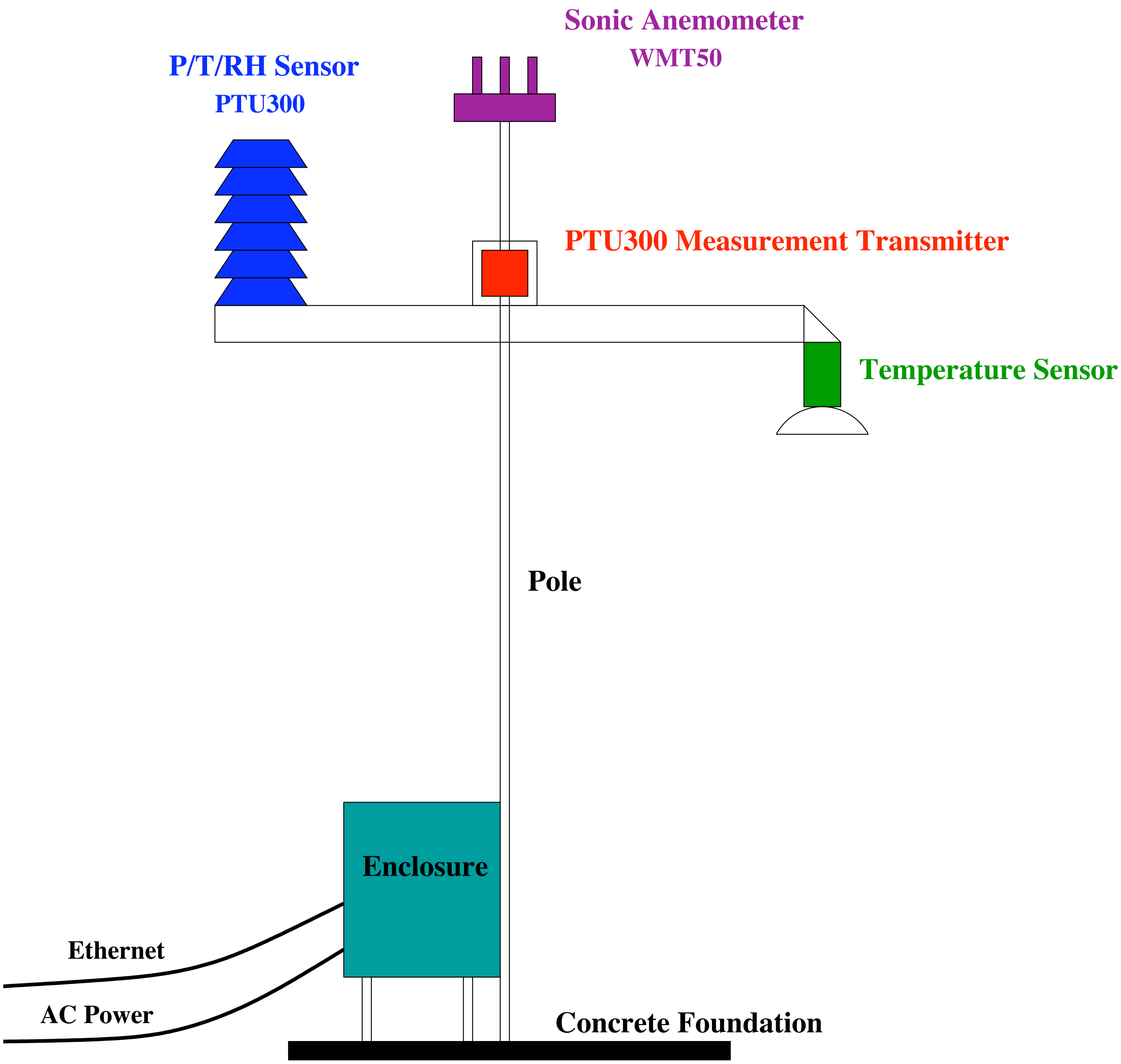

Figure 2: Sketch of a standard weather instrument installation.

Table 4: ALMA Weather Station Locations[a]

Pad Name	Pad ID	UTM-X	UTM-y	Priority[b]
West Arm				
W1	Y50	620125.00	7453657.00	1
W5	Y46	623451.00	7455040.00	1
W8	Y42	625901.90	7457210.20	1
A130	142	626124.00	7452986.00	1
South Arm				
S9	Y39	634062.00	7447310.00	1
S7	Y32	632668.20	7451111.20	1
S1	Y29	629490.20	7450388.20	1
Pampa la Bola Arm				
P13	Y28	633309.90	7462869.20	1
P10	Y24	631556.80	7458399.50	1
A129	141	628978.00	7454297.00	1
Array Center				
A71	83	627706.03	7453210.35	1
OSF	...	...	...	2

[a] Based on "configs_11Apr07.xls" spreadsheet of antenna pad locations.

[b] Installation priority.

3. Concrete base.
4. Power and ethernet access.

3.3 Instrument Accessory Enclosure

The instrument enclosure will be located at the base of the instrument mount and will house:

— Weather instrument measurement computer (SBC-GX533)
— Ethernet switch (optional)
— Network/power surge suppressor (APC SurgeArrest)
— USB to Serial converter (optional)

The specifications for the suggested vendor and model are as follows:

— Hoffman model CSD16128
— Wall-Mount Type 4/12 Enclosure
— HxWxD = 406x305x203 mm
— 16 Ga steel construction

4 Weather Instrument Data Recording and Monitoring

Each weather instrumentation tower will include an Arcom SBC-GX533 embedded linux computer in a weather protective enclosure. All weather instrumentation measurements are read at a default rate of 0.5 Hz with this computer using a simple Python script, which subsequently writes these measurements to a file. The ALMA monitor and control database then fetches the measurements by reading the output data files. Extraction and perusal of these data can then be done using a simple GUI.

The following list describes the relevant Python scripts and associated libraries and files:

ReadWS.py: Master Python script which reads the weather instruments. Uses *pyserial* library to communicate with weather devices using RS232 interface. Writes output to file *wsYYYYMMDD.dat* (time tag is MJD).

GetValues.py: Python script called by *ReadWS.py* which formats the data string read from each weather device and does a sanity check of the values.

date2MJD.py: Python script called by *ReadWS.py* which calculates Modified Julian Day.

StatusWS.py: Python script which checks the status of the weather instruments and writes this information to a file called *wsstatusYYYYMMDDhhmmss.dat* (time tag is MJD).

The format for the output weather measurement file *wsYYYYMMDD.dat* is a single line output per measurement as follows:

```
54509.6409375 Dn=245D Dm=263D Dx=278D Sn=0.0M Sm=0.1M Sx=0.1M P=  976.5hPa T= 22.4'C
TD=  5.4'C  0  0     0
```

where the values are

MJD: Modified Julian Date (days)

Dn: Wind direction minimum (deg)

Dm: Wind direction average (deg)

Dx: Wind direction maximum (deg)

Sn: Wind speed minimum (m/s)

Sm: Wind speed average (m/s)

Sx: Wind speed maximum (m/s)

P: Pressure (hPa)

T: Ambient Temperature (C)

TD: Dew Point Temperature (C)

#: WMT communications flag (0=good; 1=bad)

#: PTU communications flag (0=good; 1=bad)

#: Verification code for PTU and WMT sanity check (0=good; 1=bad)

4.1 SBC Configuration Issues

During prototyping several issues related to the setup of the SBC-GX533 were uncovered and resolved:

IRQ Assignment for CF Card: Arcom Embedded Linux (AEL) uses "IRQ-sharing" to multiplex the limited number of serial ports available on X86 hardware. With a default BIOS configuration this will result in the same IRQ being assigned to COM2 and the CF Card. You must set the IRQ used by the CF Card to something unique (like 9) or all hell will break loose.

Default Serial Port Setting: The default serial port settings are "u+rw", where the owner is root. These need to be set to "o+rw" to allow a general user account to use them.

4.2 WMT50 Instrument Readout Settings

The wind speed and direction statistical measures (minimum, maximum, and average) are calculated by the WMT50 based on settings made at the WMT50. Those settings are made with a setup command in the *ReadWS.py* script, whose values are currently as follows (see the Vaisala WMT50 Product Documentation for further information):

I: Sensor update interval (5 seconds)

A: Sensor averaging time (3 seconds)

U: Speed unit (m/s)

D: Direction correction (0 deg)

N: NMEA wind formatter (W)

F: Sensor sampling rate (4 Hz)

These setup values can be catered to the averaging method used when importing the weather station values into the metadata database.

4.3 Data File Size

The current output format (see §4) produces ascii data at a rate of approximately 188 kB per hour. It would then take approximately 444 days of continuous reading to fill 2 GB of storage. The current (test) Arcom SBC contains a 4 GB conpact flash card. A purging cron job will be developed to keep the onboard data storage at or below 2 GB.

References

[ALMA Dudes(2005)] ALMA Calibration Specifications and Requirements (2005-09-26 Draft), ALMA-90.03.00.00-001-A-SPE

[Barenburg(1974)] Barenbrug, A.W.T., 1974, "Psychrometry and Psychrometric Charts", 3rd Edition, Cape Town, S.A.: Cape and Transvaal Printers Ltd.

[Buck(1981)] Buck (1981), "New Equations for Computing Vapor Pressure and Enhancement Factor", J. Appl. Met., 20, 1527-1532

[Buck(2001)] Buck (2001), "Model CR-4 Hygrometer Operating Manual"

[Mangum(2001)] Mangum (2001), "A Telescope Pointing Algorithm for ALMA", ALMA Memo 366

[Richer & Mangum(2005)] Richer & Mangum (2005), "Ancillary Calibration Instruments: Specifications and Requirements", ALMA SCID-90-05.13.00-001-A-SPE

[Sonntag(1990)] Sonntag, D. 1990, Z. Meteorol., 70 (5), pp. 340-344, "Important New Values of the Physical Constants of 1986, Vapour Pressure Formulations based on the IST-90 and Psychrometer Formulae"

A Relationship Between Acoustic, Virtual, and Ambient Temperature

Sonic anenometers measure a quantity called the "sonic virtual temperature". This sonic virtual temperature is defined as

$$T_{sv} = a\left(v_s^2 + v_n^2\right) \tag{1}$$

where v_n is the velocity component normal to the sonic path used to measure the speed of sound, $a = 2.48 \times 10^{-3} Ks^2/m^2$, and v_s is the speed of sound. T_{sv} is simply the temperature associated with the sound speed in the gas. Note that the sonic anemometer outputs three orthogonal wind components (u,v,w) plus the speed of sound, v_s. This means that v_n is defined as follows

$$v_n^2 = v^2 + \frac{(u+w)^2}{2} \tag{2}$$

This sonic virtual temperature is related to a fictitious temperature used by meteorologists called the "virtual temperature". The virtual temperature is defined as the temperature that dry air would have if its pressure and specific volume were equal to those of a given sample of moist air. Basically, the virtual temperature construct allows meteorologists to use the equation of state for dry air even though moisture is present. The virtual temperature T_v is related to the sonic virtual temperature T_{sv} as follows

$$T_{sv} = T_v\left(1 + 0.32\frac{e}{P_s}\right) \tag{3}$$

where e is the vapour pressure (in mb), P_s is the absolute pressure (in mb), and the temperatures are in degrees K. The relationship between T_v and ambient temperature T_s is

$$T_s = T_v\left(1 + 0.378\frac{e}{P_s}\right) \tag{4}$$

where the units and symbols are the same as in the relation between T_{sv} and T_v.

In summary, the USA-1 sonic anomemeter will measure T_{sv}, which is related to T_s as follows

$$T_s = T_{sv}\left[\frac{\left(1 + 0.378\frac{e}{P_s}\right)}{\left(1 + 0.32\frac{e}{P_s}\right)}\right] \tag{5}$$

B Relationship Between Relative Humidity, Dew Point Temperature, and Surface Temperature

There are several rather good expressions for the vapour pressure above water (e_w in mb) or ice (e_i in mb) that one can use to relate the relative humidity (RH), dew point temperature (T_{dp} in C), and surface air temperature (T_s in C) (see [Buck(1981)], [Buck(2001)], [Barenburg(1974)] (for the Magnus-Tetens formula), and [Sonntag(1990)]). The Buck formalism is a bit different in that it includes a slight ambient pressure (P in hPa) dependence which is quantified in terms of an "enhancement factor" (EF[2]). These relations for e_w or e_i can be used in the following to derive the RH in terms of T_{dp} and T_s:

$$RH = 100 \times \frac{e_w(T_{dp})}{e_w(T_s)} \tag{6}$$

$$= 100 \times \frac{e_i(T_{dp})}{e_i(T_s)} \tag{7}$$

where the Buck relations are given by:

$$e_w^{Buck}(T) = EF\left\{6.1121\exp\left[\left(18.678 - \frac{T}{234.5}\right)\left(\frac{T}{T+257.14}\right)\right]\right\} \tag{8}$$

$$e_i^{Buck}(T) = EF\left\{6.1115\exp\left[\left(23.036 - \frac{T}{333.7}\right)\left(\frac{T}{T+279.82}\right)\right]\right\} \tag{9}$$

$$EF = 1 + 10^{-4}\left[2.2 + P\left(0.0383 + 6.4\times10^{-6}T^2\right)\right] \tag{10}$$

the Magnus-Tetens relations are given by:

$$e_w^{Magnus}(T) = 6.1121\exp\left[\left(18.678 - \frac{T}{234.5}\right)\left(\frac{T}{T+257.14}\right)\right] \tag{11}$$

$$e_i^{Magnus}(T) = 6.1115\exp\left[\left(23.036 - \frac{T}{333.7}\right)\left(\frac{T}{T+279.82}\right)\right] \tag{12}$$

and the Sonntag relations are given by:

$$\ln\left(\frac{e_w^{Sonntag}(T)}{100}\right) = \frac{-6096.9385}{T} + 21.2409642 - 0.02711193T + 1.673952\times10^{-5}T^2 + 2.433502\ln(T) \tag{13}$$

$$\ln\left(\frac{e_i^{Sonntag}(T)}{100}\right) = \frac{-6024.5282}{T} + 29.32707 - 0.010613868T - 1.3198825\times10^{-5}T^2 - 0.49382577\ln(T) \tag{14}$$

$$\tag{15}$$

Plots of the RH calculated for each of these expressions and the percentage difference between them are shown in Figures 3 and 4.

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[2] Note that the equation for EF in [Buck(2001)] contains two typographical errors.

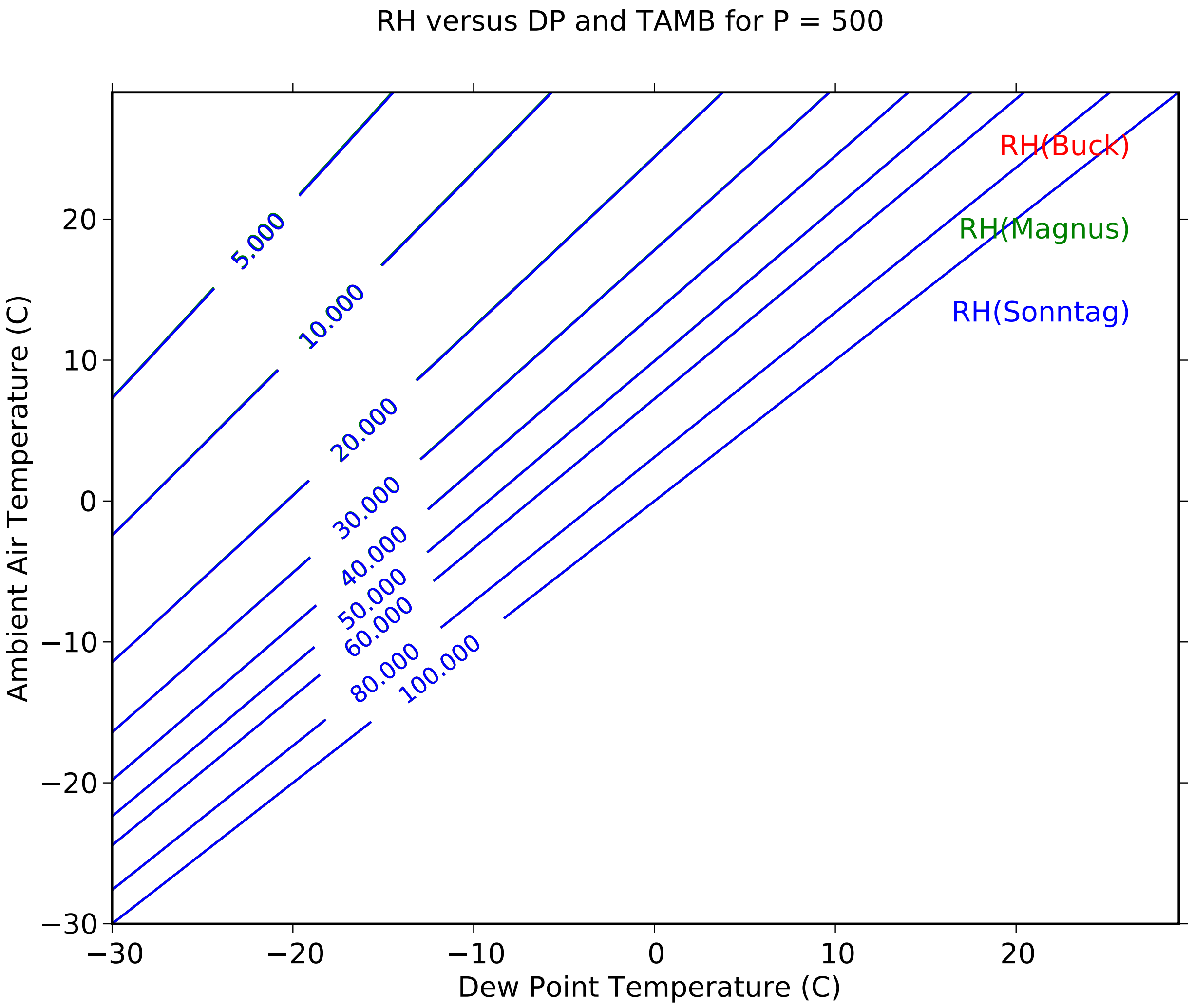

Figure 3: Plot of RH versus T_{dp} and T_s for all three developments of e_w. Note that only the upper-left half of the plot is relevant (since $T_{dp} < T_s$ always). Note how all three developments yield nearly identical results.

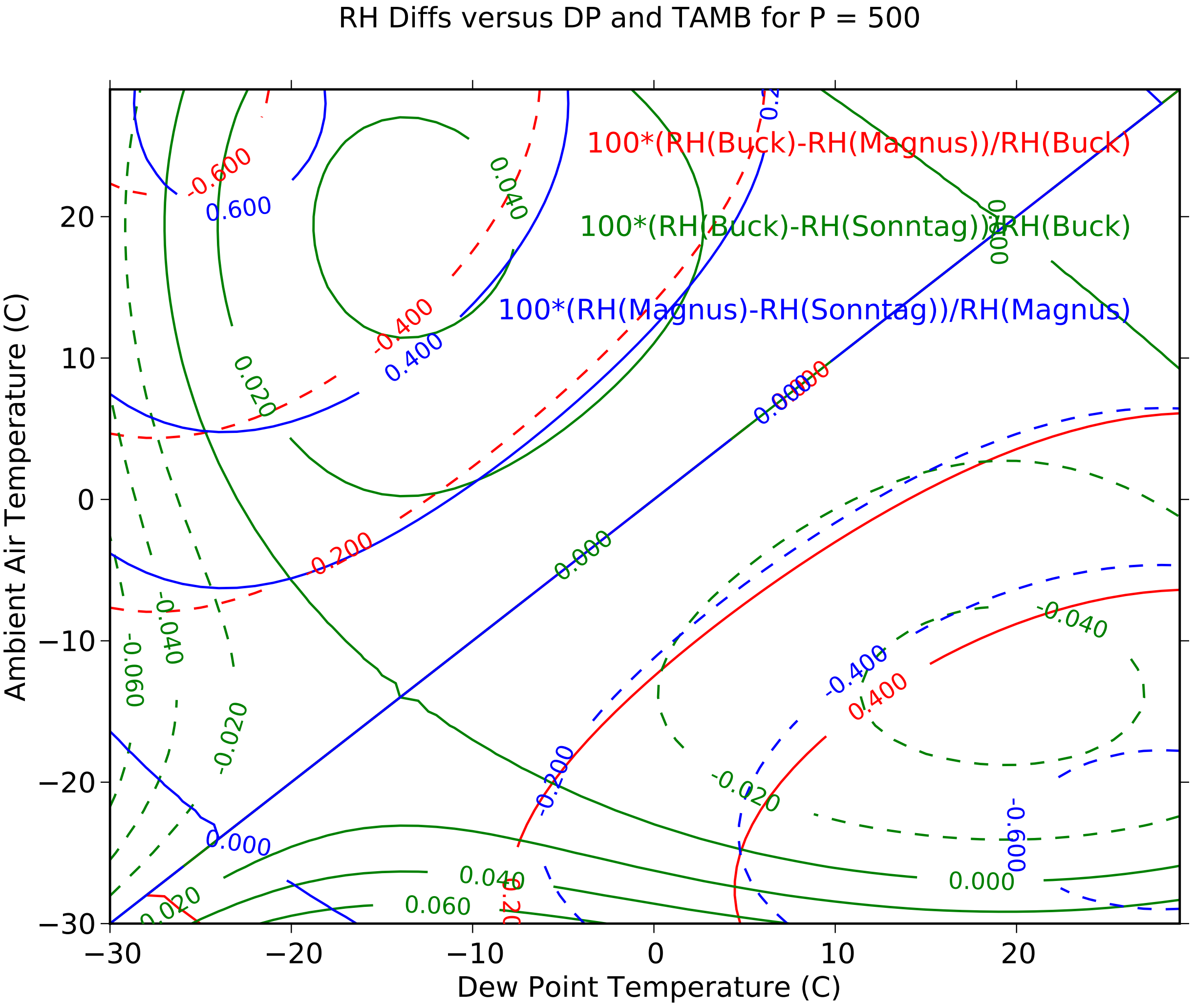

Figure 4: Plot of the percentage difference between the RH derived from the three developments of e_w versus T_{dp} and T_s. Note that only the upper-left half of the plot is relevant (since $T_{dp} < T_s$ always). At most there is a 0.6% difference between the three.