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Water Cycle at Mars - Gale crater example through MSL/REMS-H

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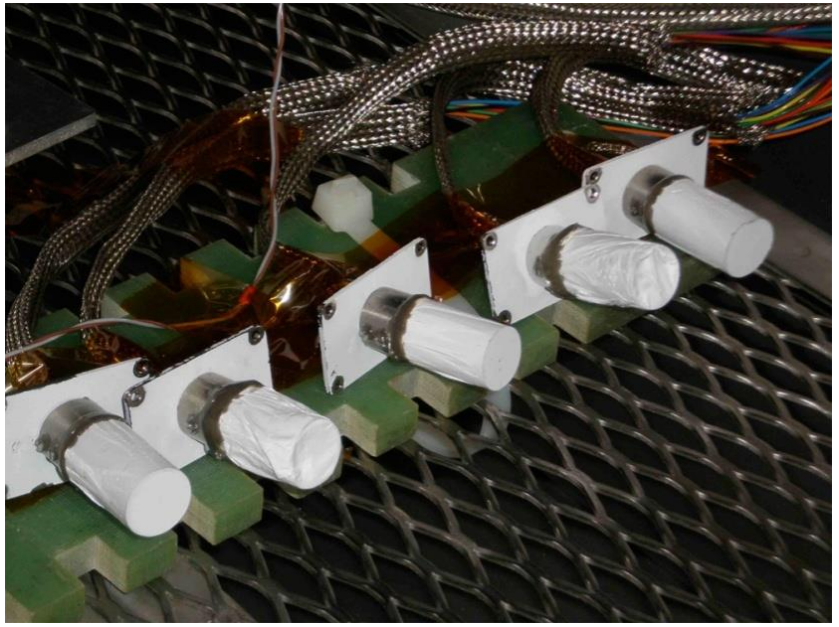
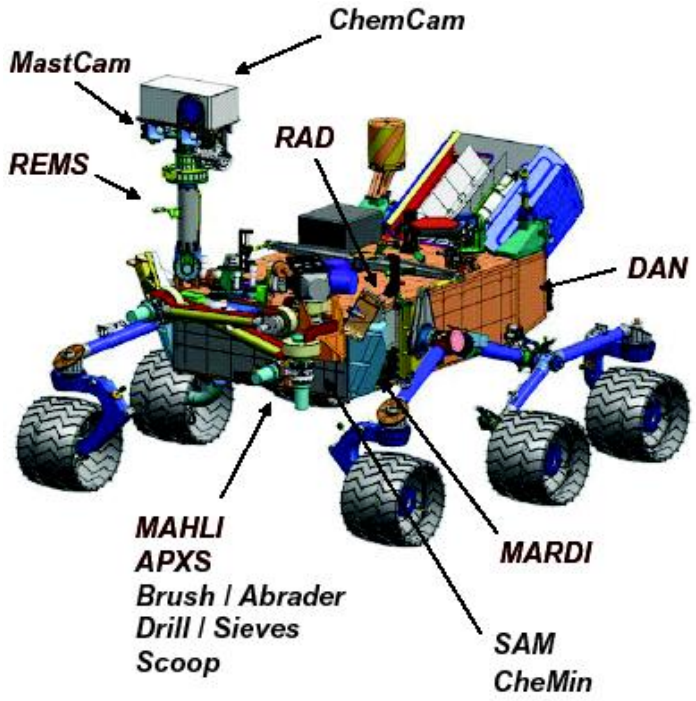
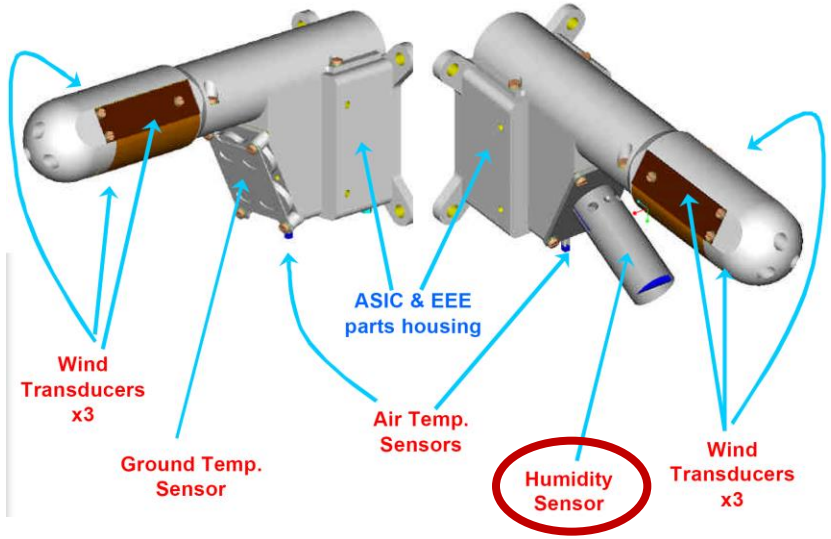
REMS-H Humidity Instrument

REMS-H is located in Boom 2 of the Curiosity rover and therefore under large temperature oscillations. Validation technology tests carried out to assure no degradation along its operational life.

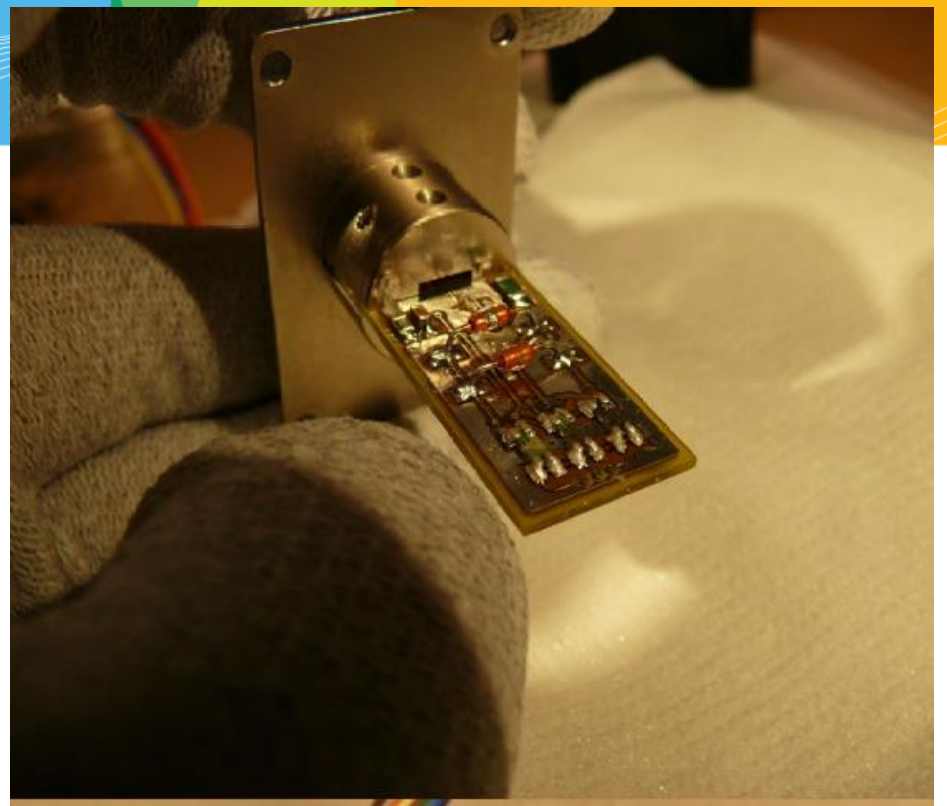


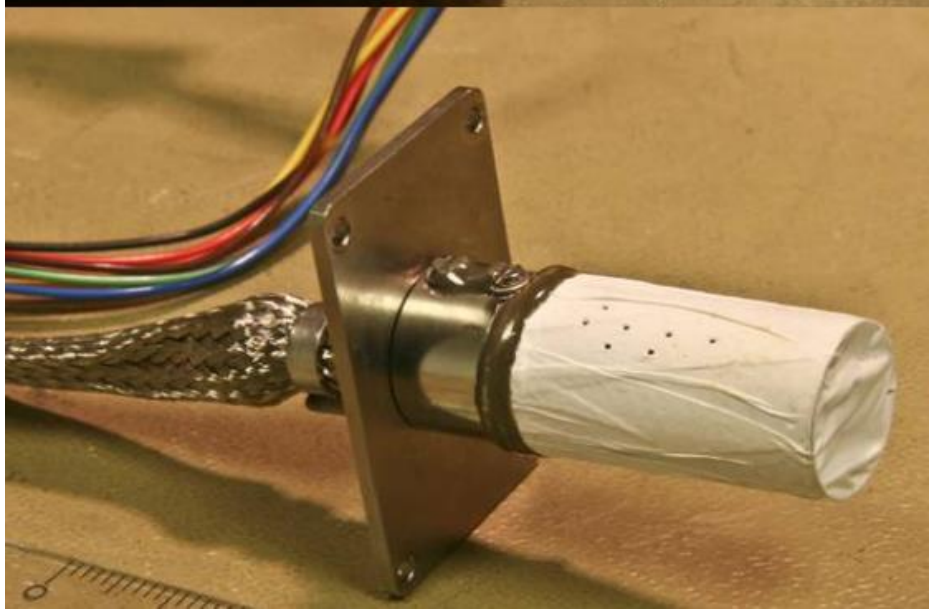




REMS-H Resource Reqs

- Passive device
- Mass 15g
- Power 15 mW
- Volume
  - Tube 40 x Ø16 mm
  - Support 40 x 25 mm
  - Sensor 1.5 x 4 mm (head, heater, pads)



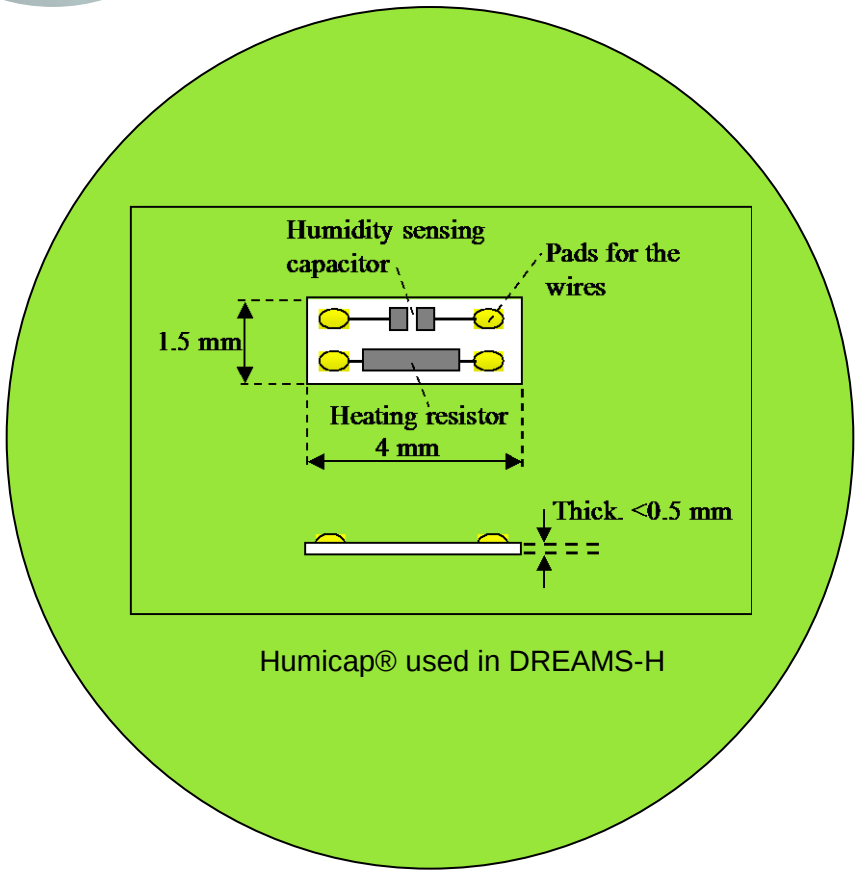


Humicap®

Humicap® humidity sensor chip is a capacitive sensor. It contains an active polymer film that changes capacitance as function of relative humidity and temperature. The capacitance is also affected by CO2 gas.

Accurate housekeeping temperature measurements as close to Humicap® as possible are needed to interpret the humidity results. In DREAMS-H these measurements are performed with Vaisala Thermocap® capacitive sensor placed on the PCB close to the Humicaps.

Humicap® can be regenerated or defrosted with an integrated heating resistor.

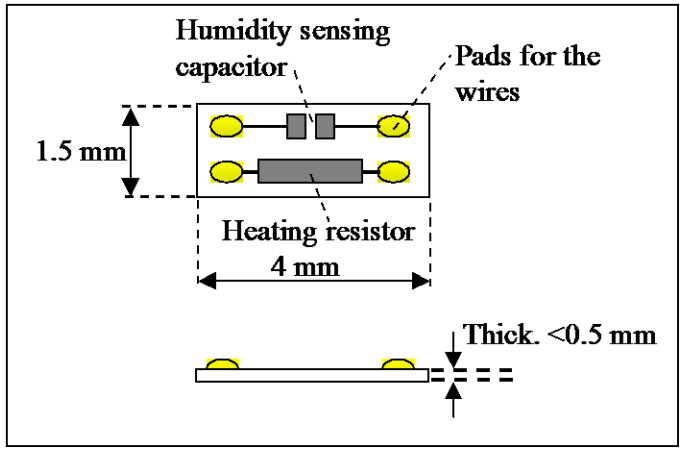


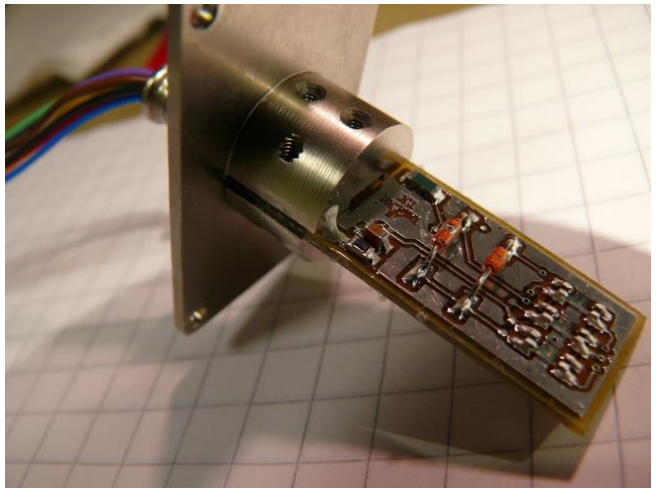
Humicap® used in DREAMS-H

REMS-H Technology

Humicap® Humidity Sensor Heads

- REMS-H measures the ambient humidity with three (3) indentical Humicap® sensor heads manufactured by Vaisala Oy (Finland).
- Humicaps are based on capasitic sensor technology as are the Barocaps of REMS-P.
- The ambient humidity affects the active polymer film that changes the capacitance of the Humicap sensor head. This change of the capasitance is measured and processed to humidity reading.
  - For reduntancy, all three Humicap sensor heads are measured at the same time.
- Each Humicap® includes a heating resistor that is heated from time to time for sensor head regeneration purposes.

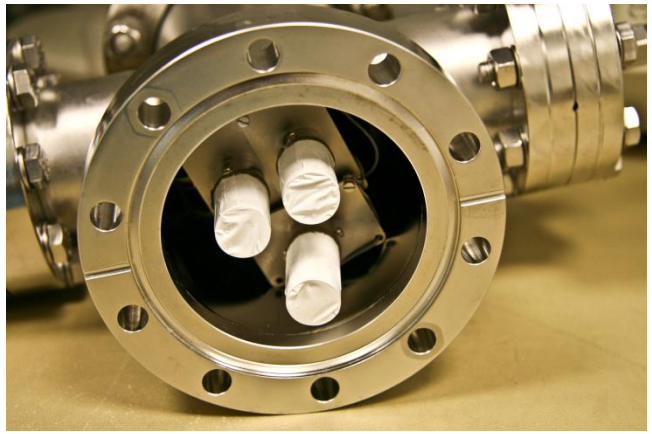




REMS-H Calibration Description

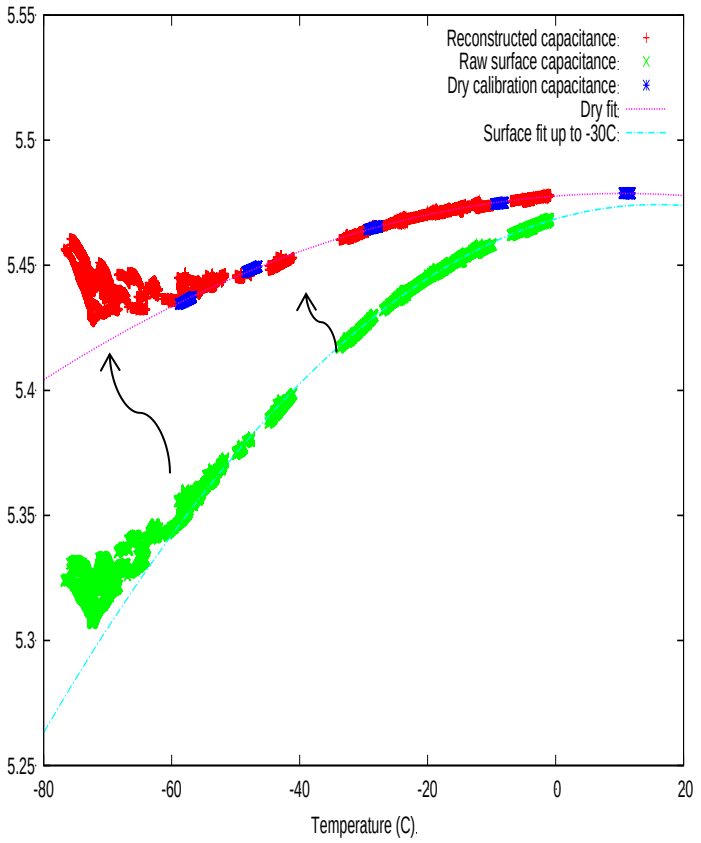
REMS-H Calibration

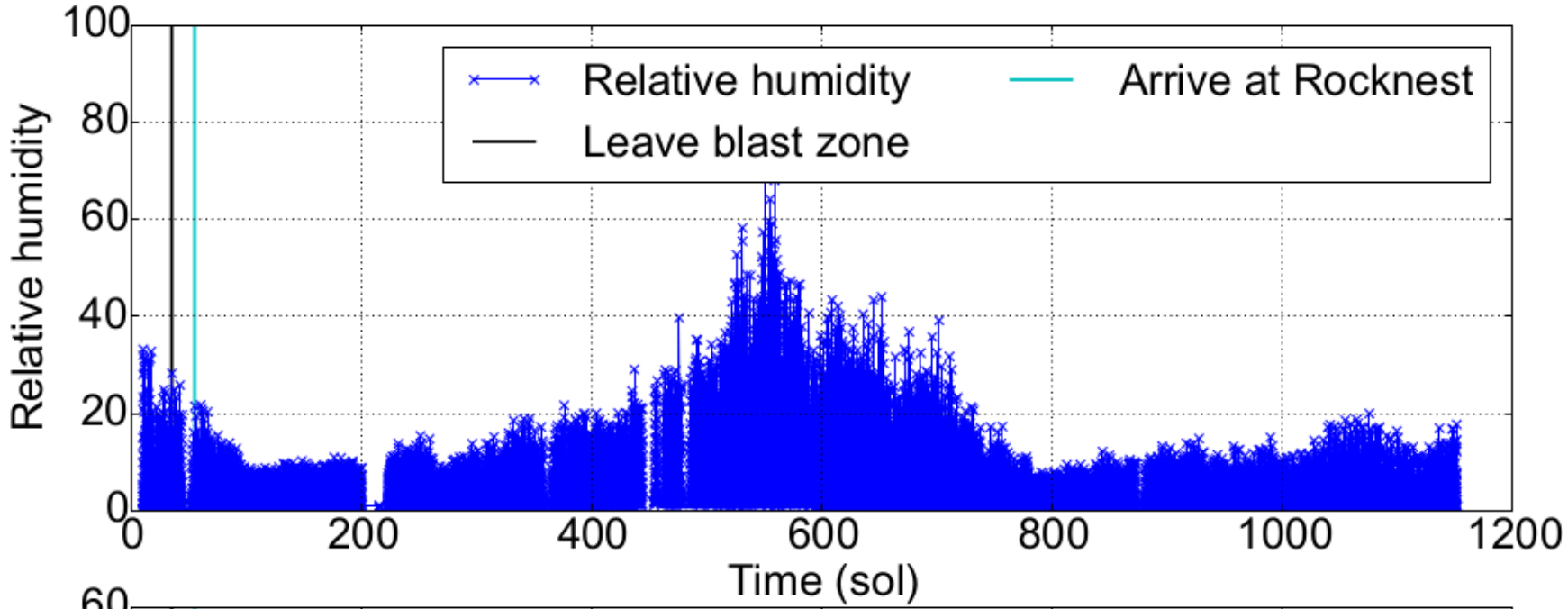
- The Humidity sensor calibration has been performed in two steps:
  1. Temperature calibration. Calculate calibration coefficients of the sensor heads and measure the resistance of the resistors in the operational temperature range (-70° C to +25° C);
  2. Humidity calibration: basic calibration in room temperature, dry points (vacuum) in < 0° C, wet points (~100%RH) in <0° C, intermediate humidity points in <0° C.
- The REMS-H nominal resolution is < 0.5% RH and nominal accuracy <8 % RH down to -70° C (specification).
- The dust filter around the REMS-H does not pose obstacles on the sensor performance.

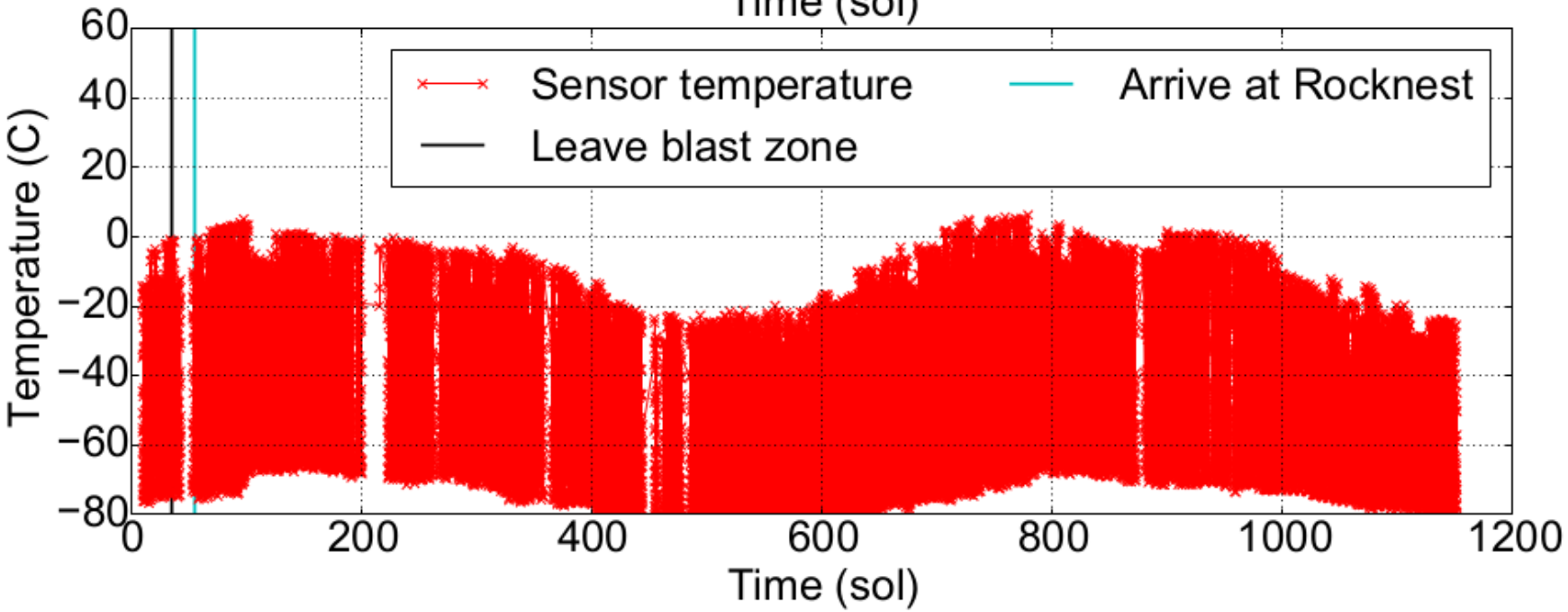


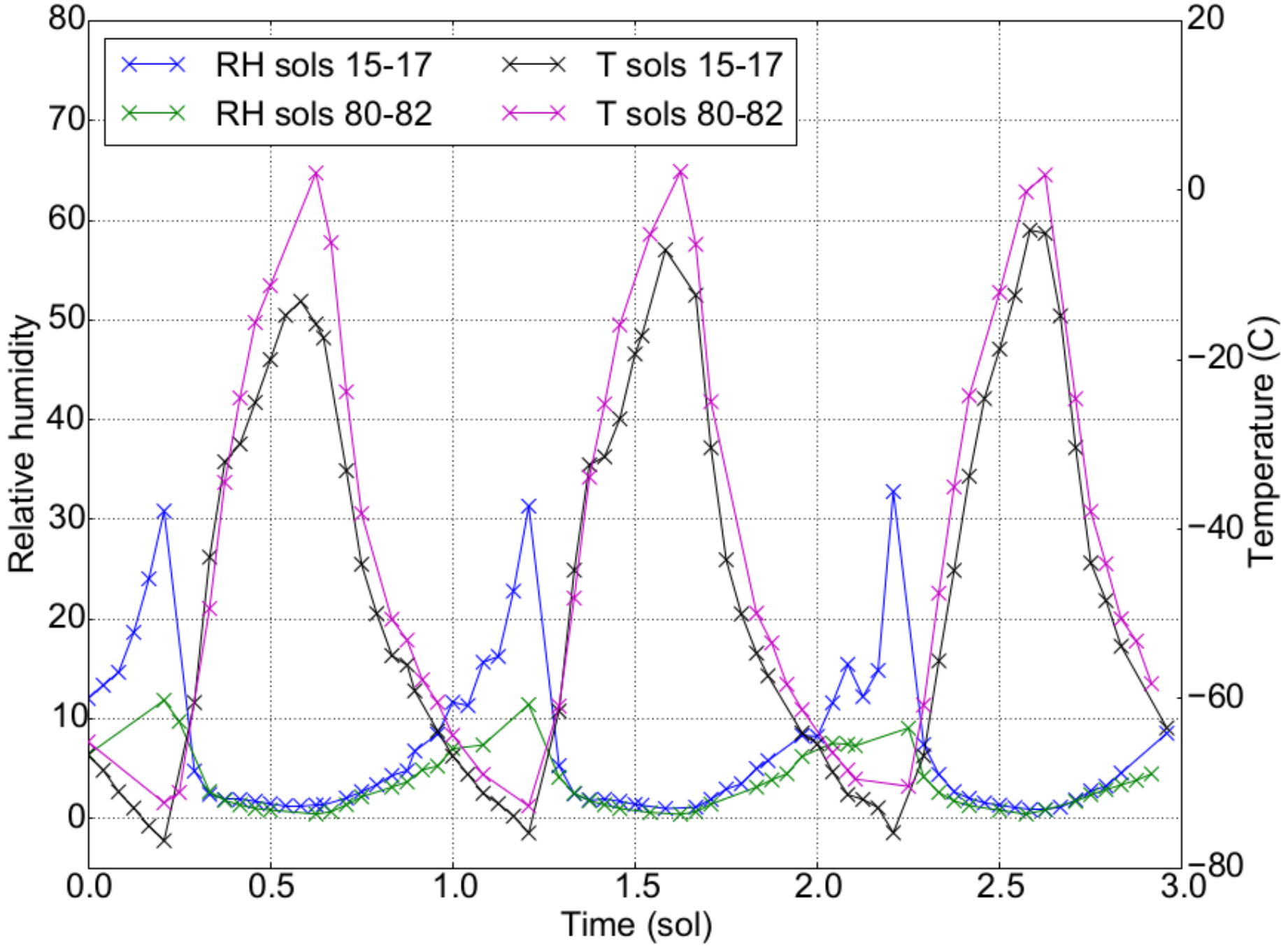
Recalibration for the CO2 & artifact -effects, part 2

- The capacitance curve is adjusted so that it follows dry calibration curve down to -30° C to provide compensated sensor readings
- Calibration coefficients and PTFE filter compensation are then applied to these readings to provide humidity values
- *Preliminary measurements : The 100% humidity in CO2 behaves such that the sensor head dynamics of the original calibrations are valid.*

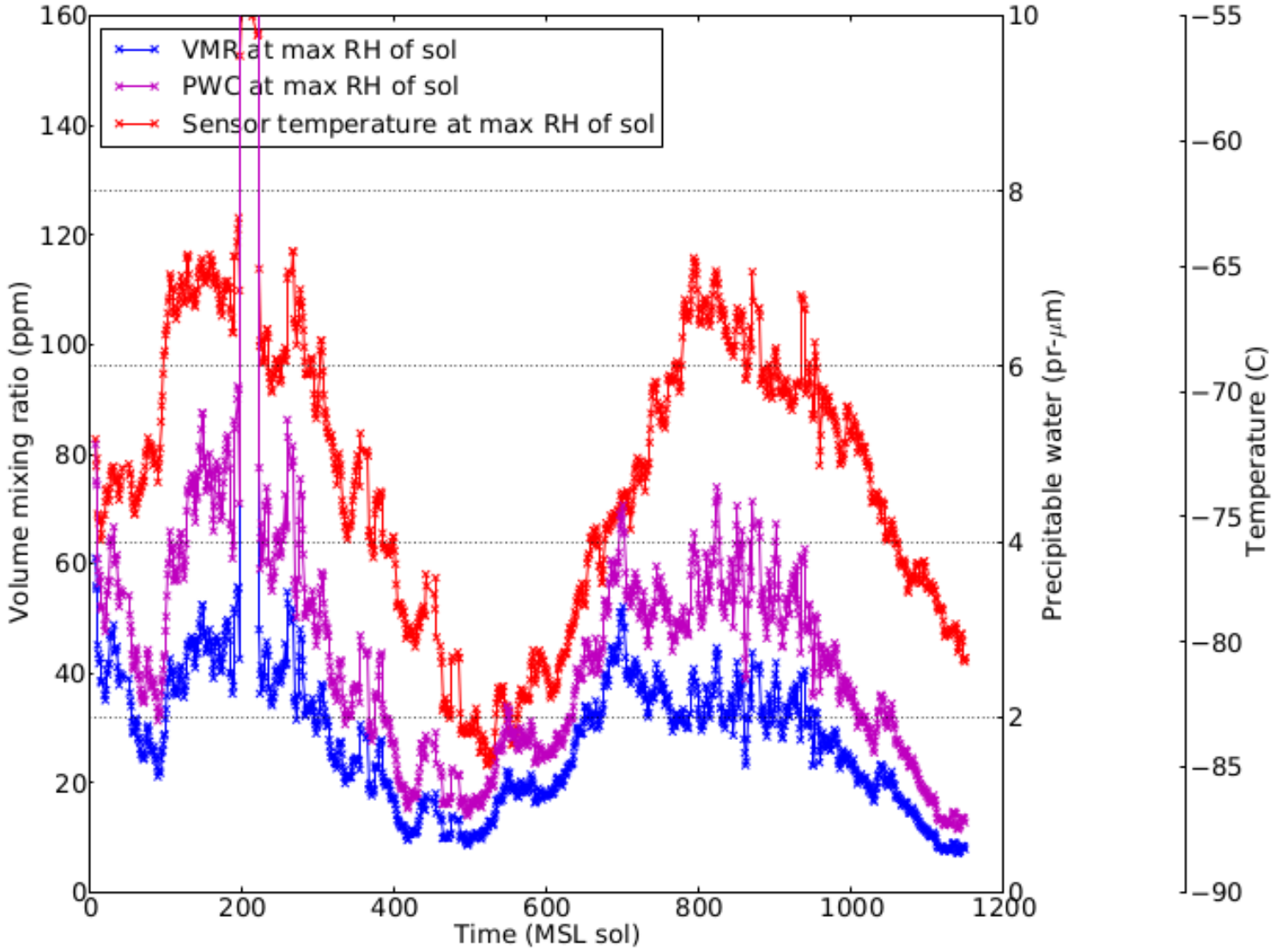



Relative humidity
Arrive at Rocknest
Leave blast zone
Relative humidity
Time (sol)
0
20
40
60
80
100
0
200
400
600
800
1000
1200

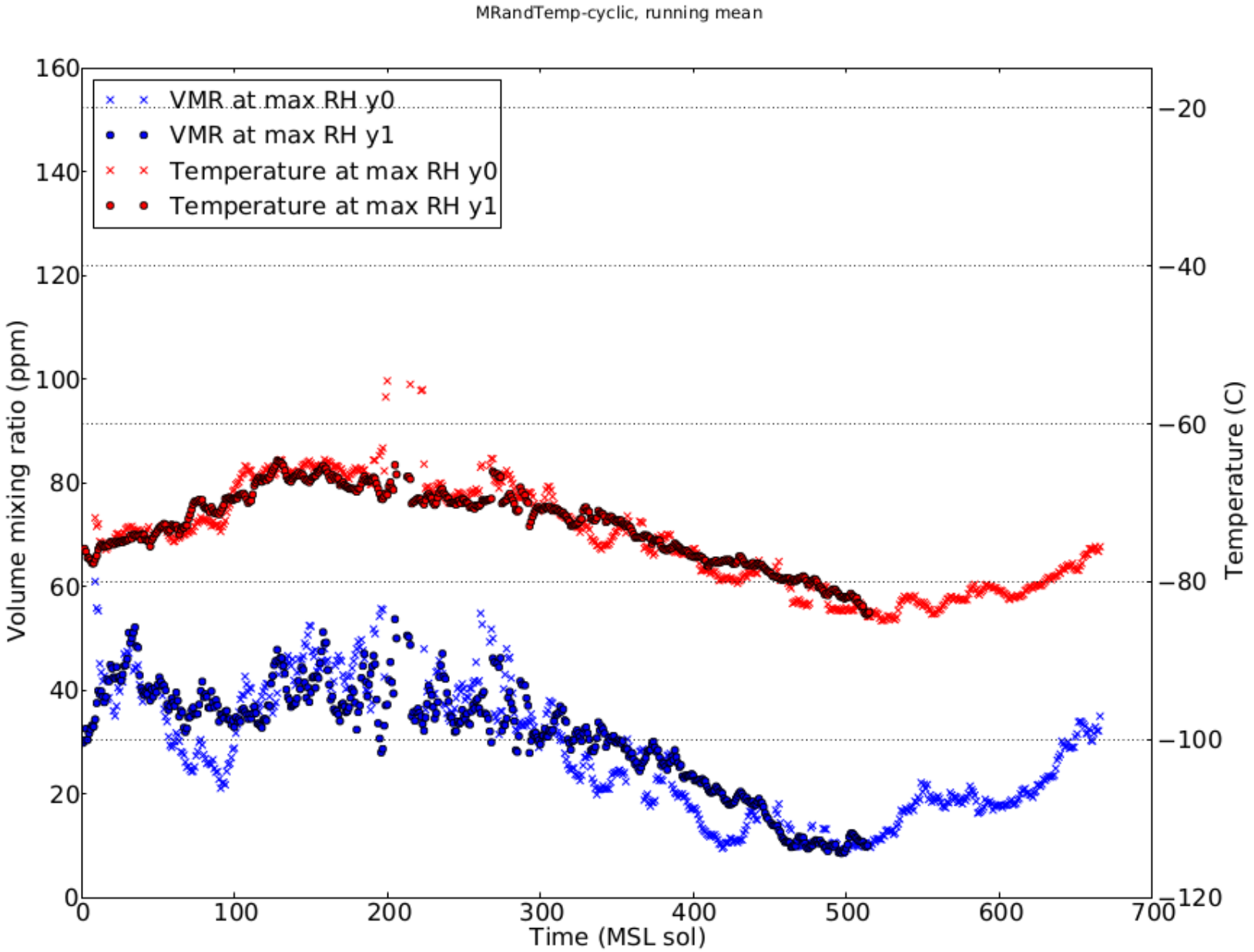

Sensor temperature
Arrive at Rocknest
Leave blast zone
Temperature (C)
Time (sol)
60
40
20
0
−20
−40
−60
−80
0
200
400
600
800
1000
1200


RH sols 15-17
RH sols 80-82
T sols 15-17
T sols 80-82
Relative humidity
Temperature (C)
Time (sol)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
10
20
30
40
50
60
70
80
−80
−60
−40
−20
0
20

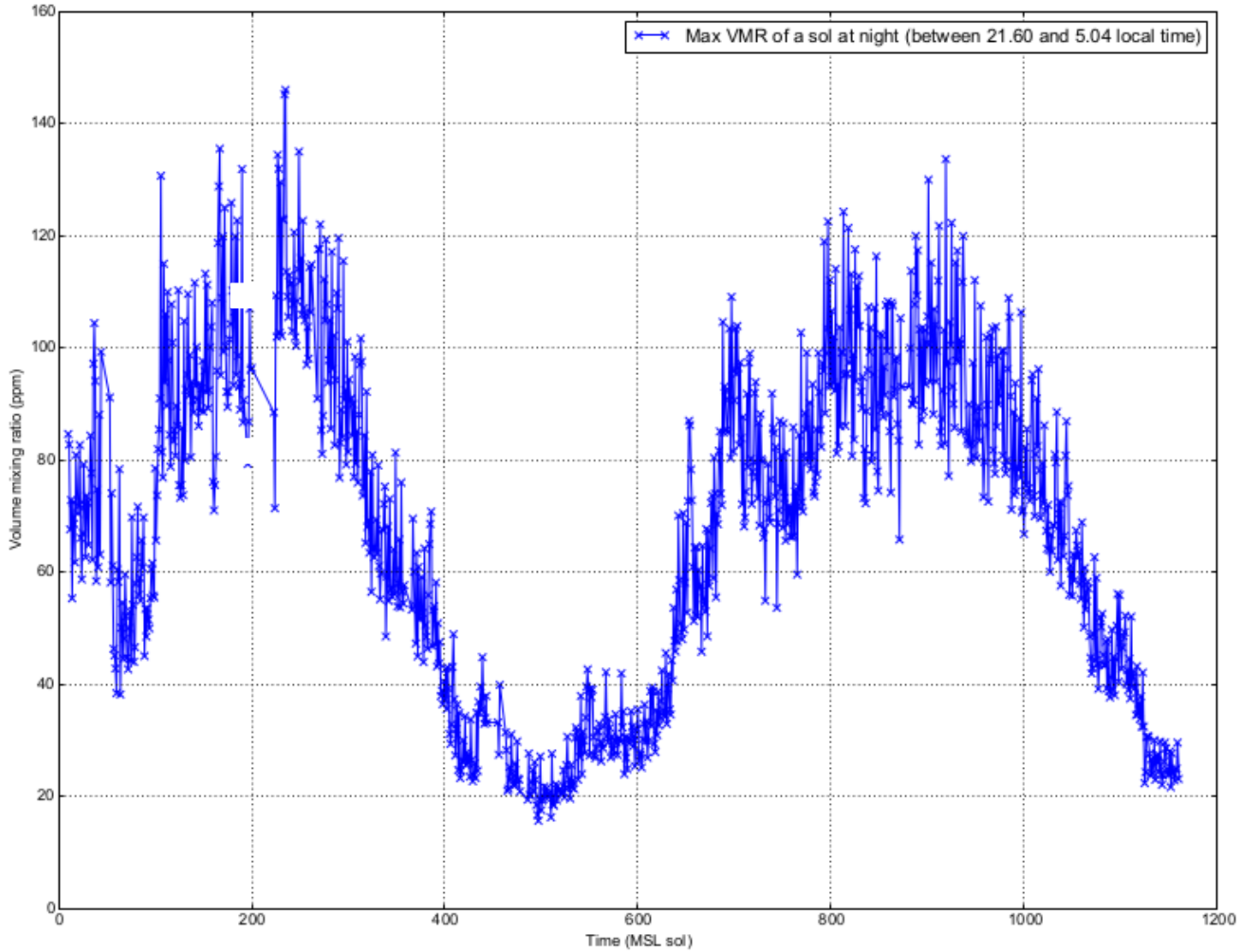
Late night/predawn VMR/T/PWC, two years



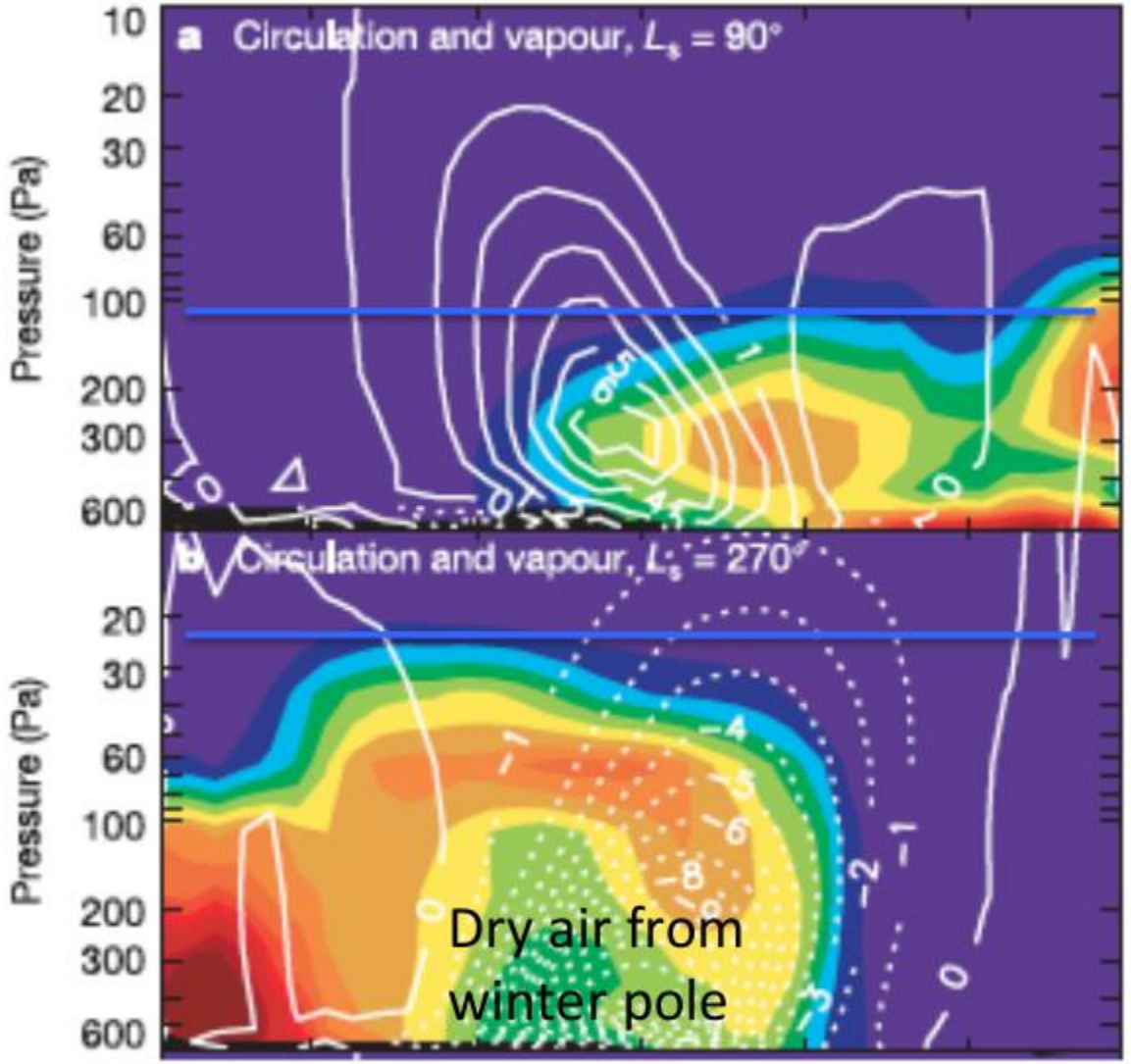
Late night/predawn VMR, two years



VMR at late evening (22-24 LT)

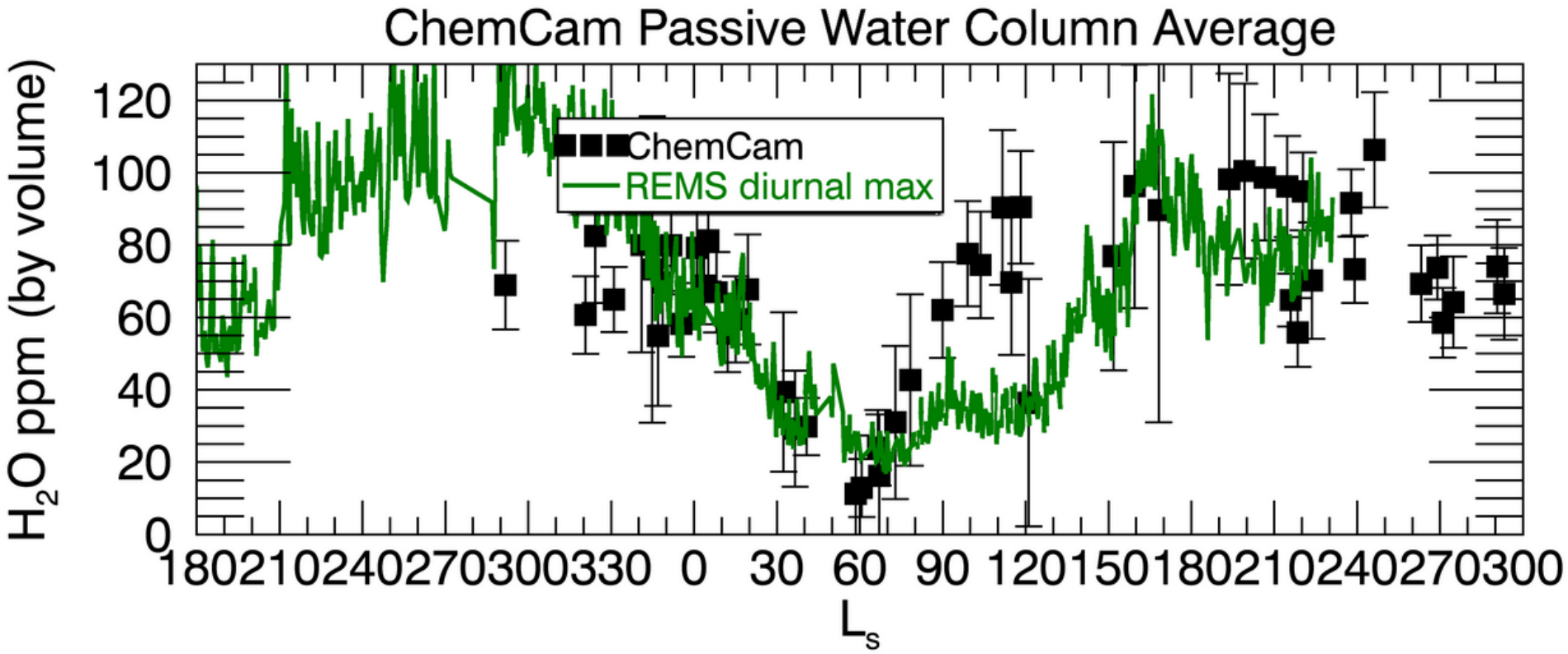


Modelled Annual water distribution (Ls 90 & 270)

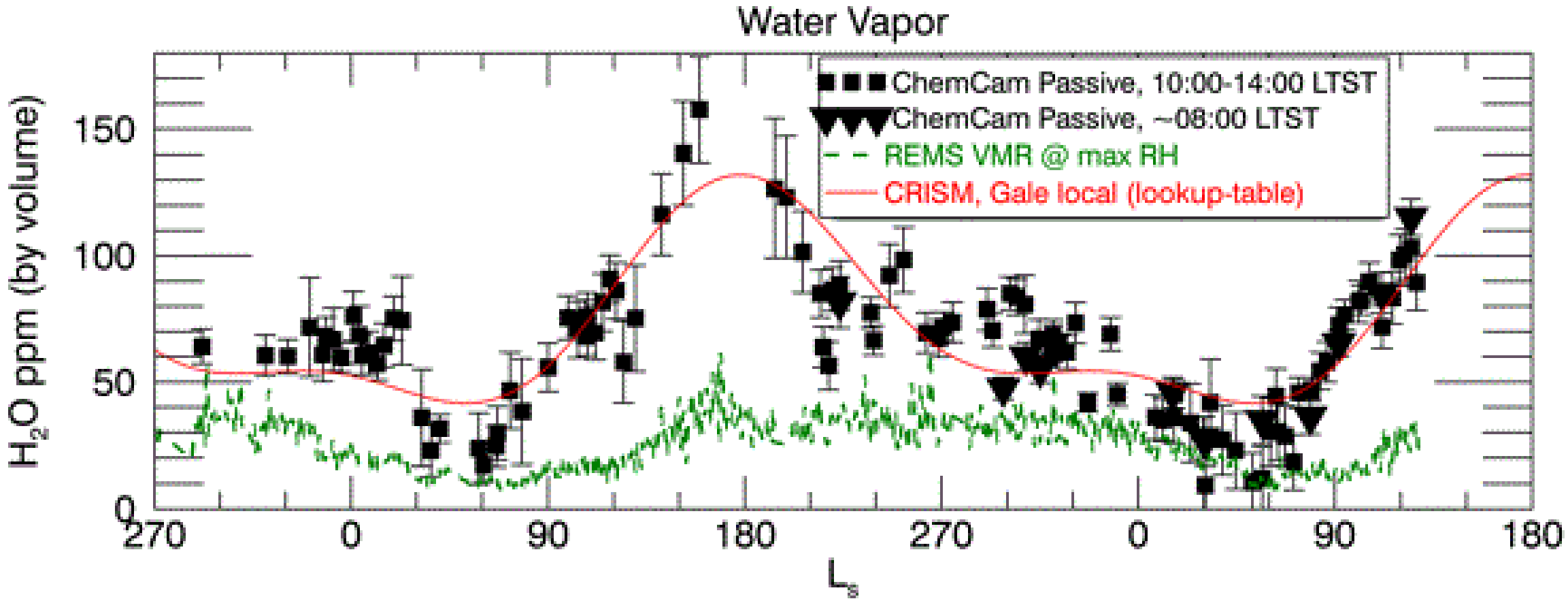


Richardson and Wilson, 2002

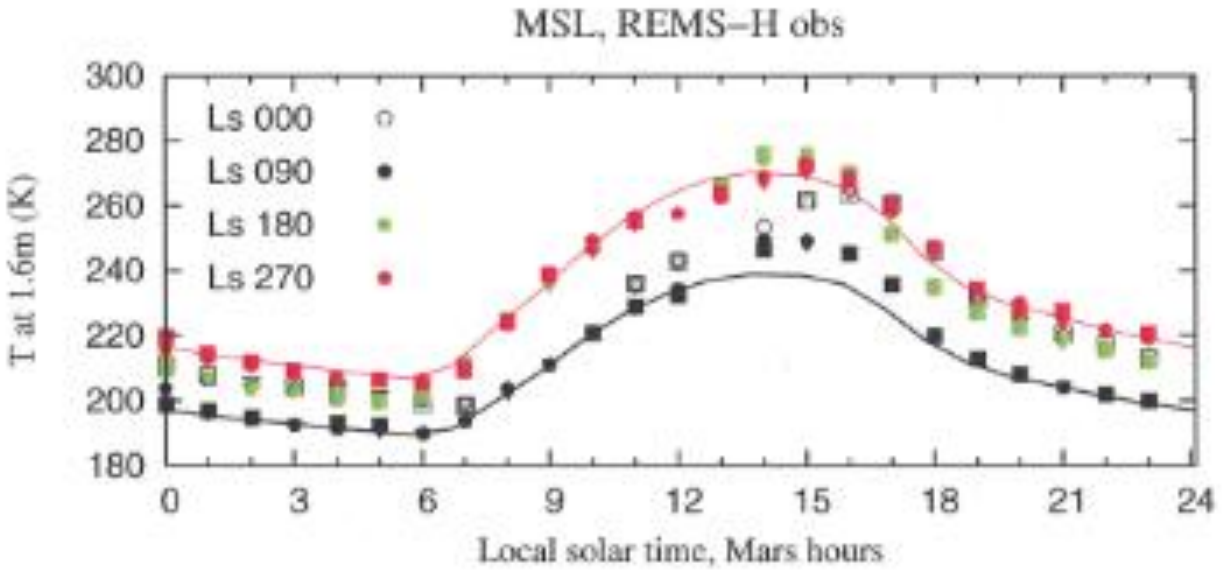
REMS-H & CHEMCAM Passive Sky Obs

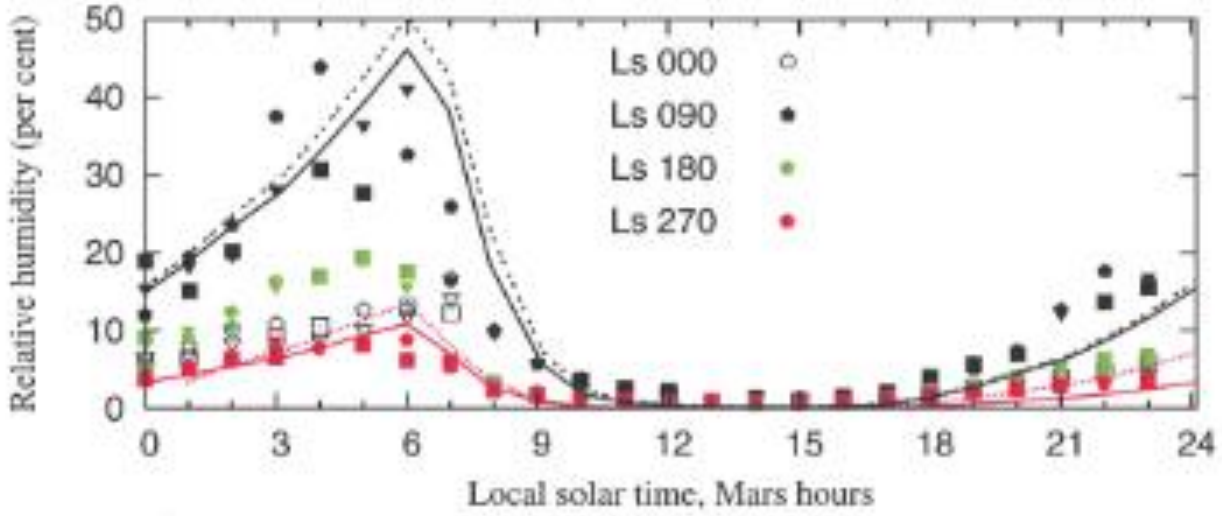


REMS-H PreDawn & CHEMCAM Passive Sky AVE Obs

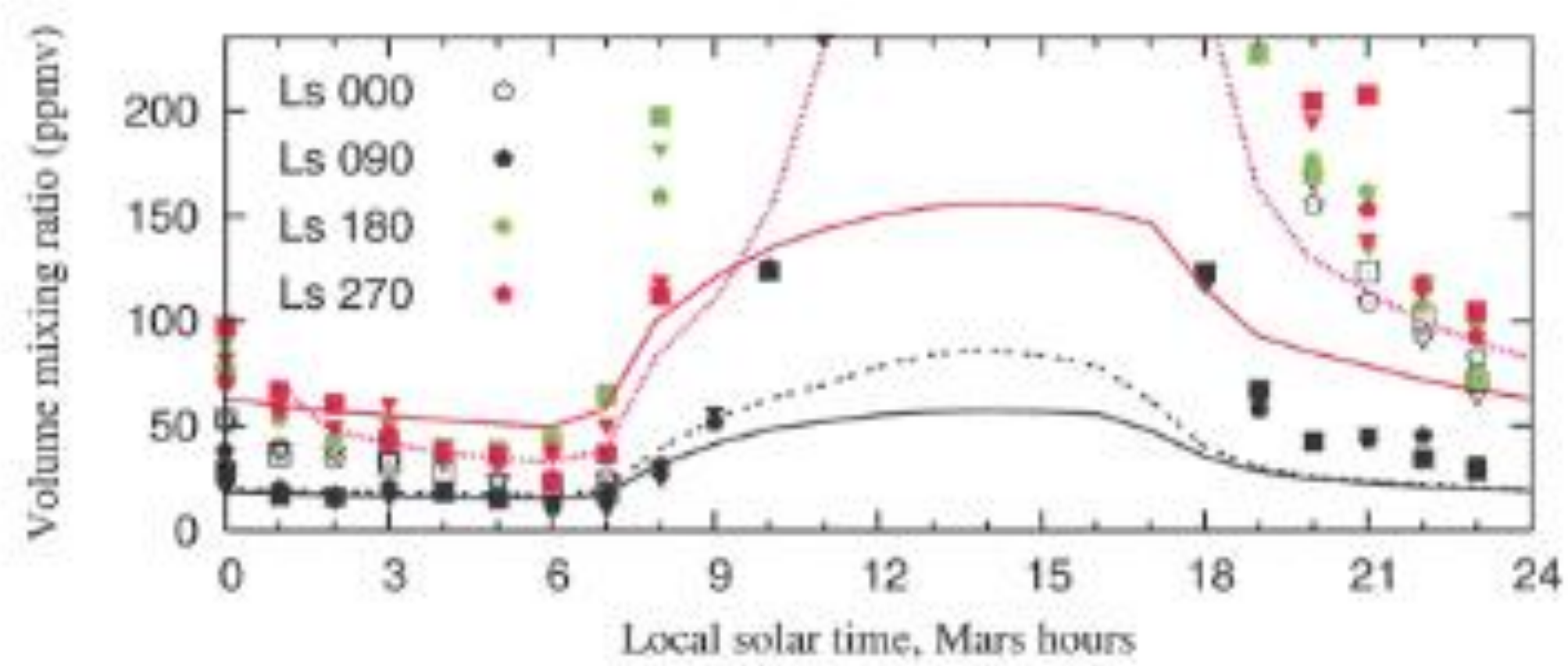


REMS-H Obs : RH and T





REMS-H VMR – Obs & Model



Concluding remarks

- MSL/REMS-H: Two full Martian years of observations – the longest in situ humidity data record
- Substantial exchange of water between the atmosphere and regolith seems to be taking place - can be explained by adsorption/desorption processes
- REMS-H observations aligned with MSL/CHEMCAM and GCM modelling results
- VMR of daylight atmospheric near-surface humidity seems to vary seasonally from about 20 to (100-140) ppmv
- Modelling of diurnal VMR variation under way. Preliminary results indicate the variation of roughly (Ls 90) 15-60 ppm and (Ls 270) 30-120 ppm

Additional slides

Nominal humidity data processing

1. Capacitances of Humicaps and Thermocap are calculated with help of reference channels. This proprietary algorithm by Vaisala is also used in REMS Pressure sensor.
2. Calibration coefficients calculated from calibration measurements are applied to the capacitances => the results are Temperature in ˚C and Relative humidity in % (relative to ice).
3. In dynamic conditions (always on Mars), correction to compensate for PTFE filter effects and Humicap® slow response in cold is applied

- **Note**: the resulting relative humidity is related to the temperature of the sensor, not of atmosphere. Further (straightforward) data processing using atmospheric pressure and temperature measurements is needed to get RH of atmosphere.

Situation after landing

- No change in HS hardware status since landing
  - All 3 Humicap sensor heads behave on Mars in similar fashion (close to each other) as in calibration, STT and cruise

    => This indicates that the sensor heads are intact
  - The lower reference channel seems to have changed its temperature dependence compared to the sensor level and boom level tests (details on slide 8).

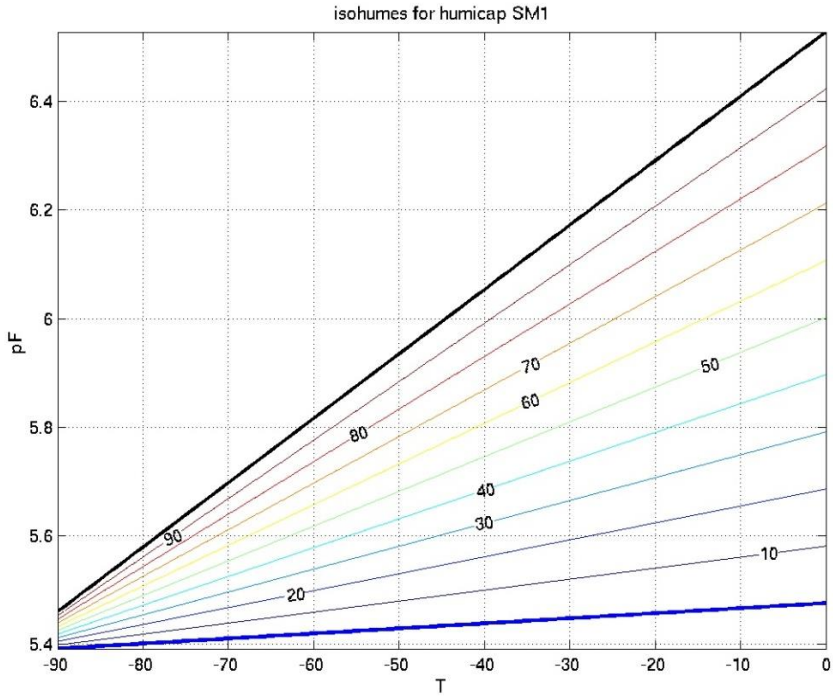
    •This was seen already in STT and cruise, but at that time it seemed to be easy to compensate by using spare housekeeping channel as reference
  - Also another ”transducer artifact” was seen after landing (details on slide 9)

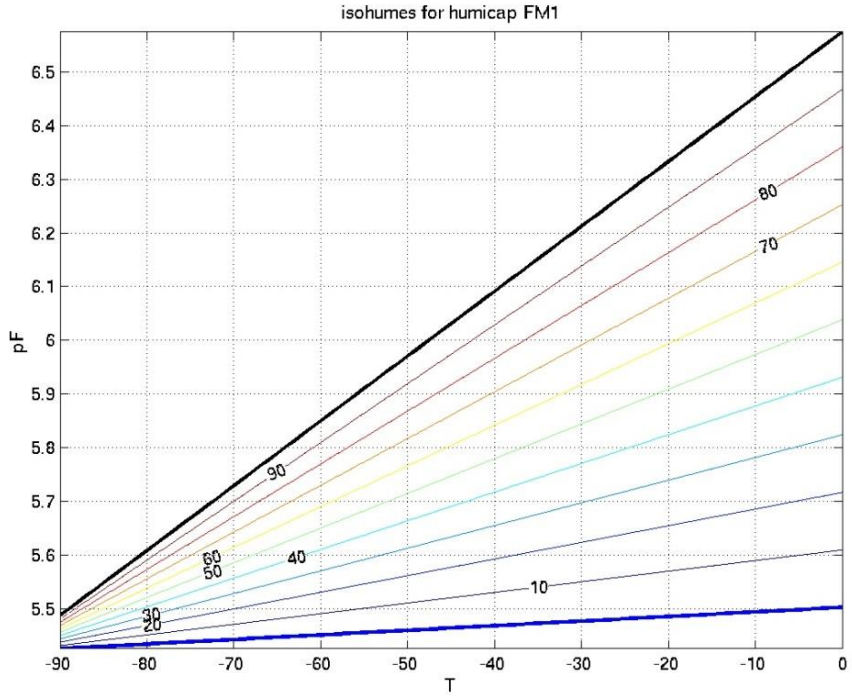
    ⇒The calibration coefficients are not usable as such

    We have not yet been able to reproduce this behaviour on reference model or any other HS models (nor by analysis)

REMS-H Calibration Description (cont.)

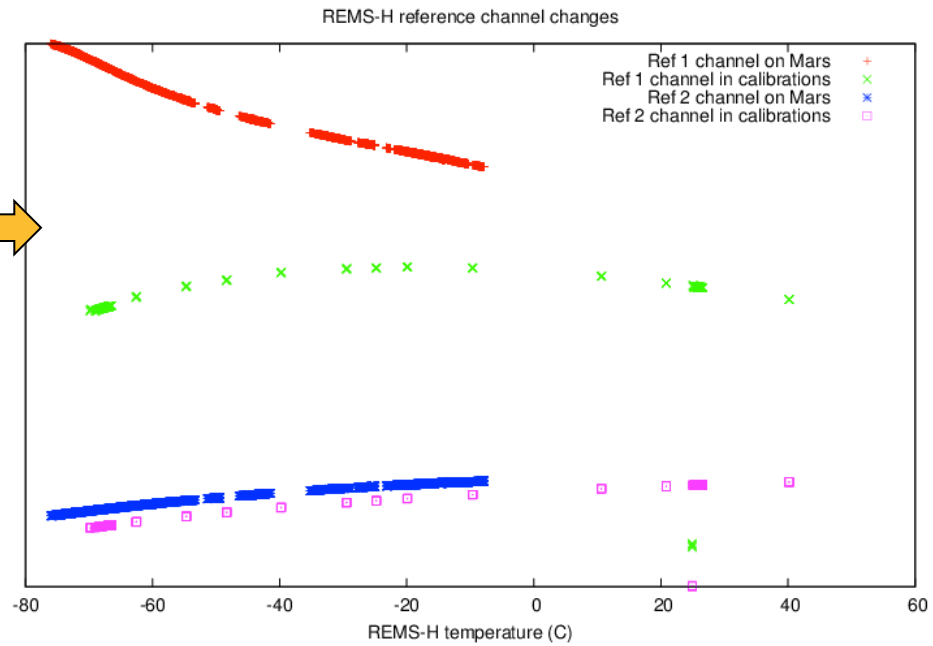
Isohumes calibration results for REMS-H FM and SM models. RH is relative to ice.



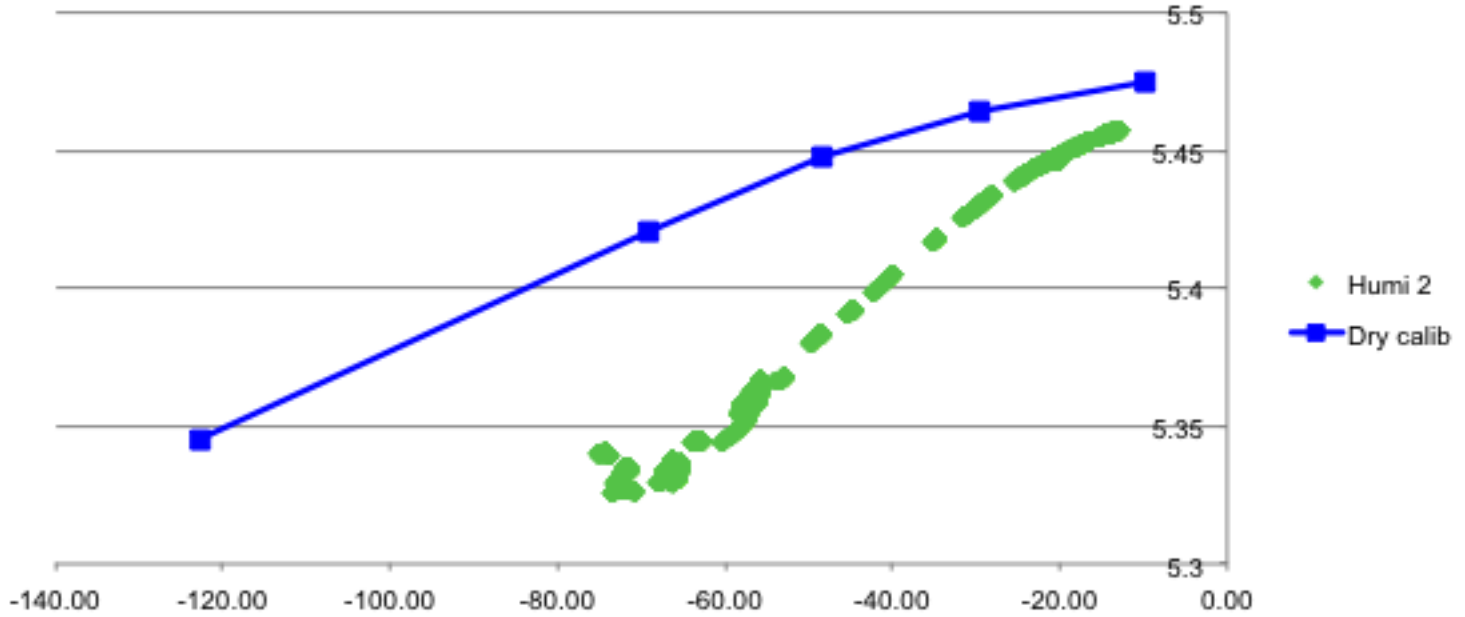


Lower reference channel behavior

- Temperature dependence of one ref. channel has apparently changed
  - It curves the ”wrong way” (compare red vs. green in the plot)
  - Seen already in STT
  - Other channels seem to behave as they should (for example blue vs purple)
- Compensation => use spare housekeeping constant channel as a reference channel and re-calculate calibration coefficients

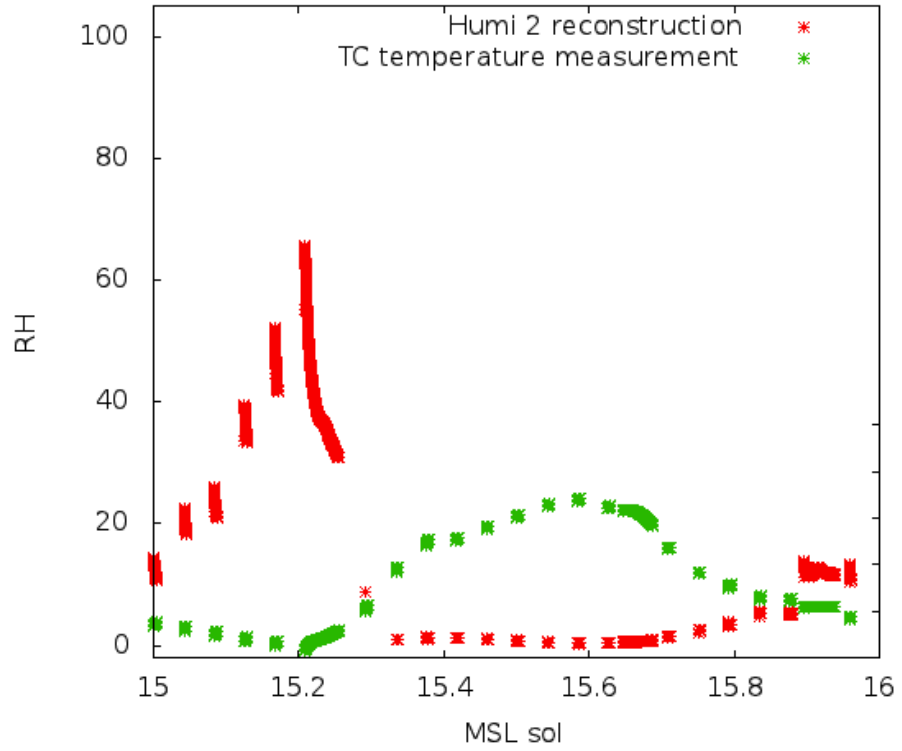


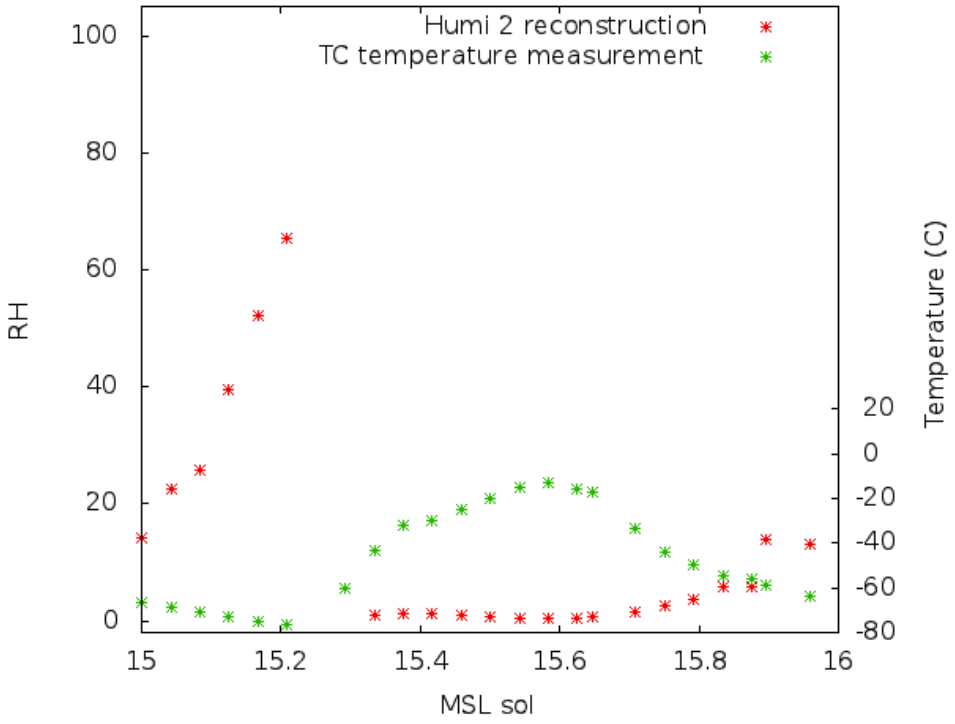
Humicap capacitance on Mars vs in dry calibration



- Because of unknown transducer electronics artifact, the capacitances seem to be lower than during dry calibration => directly calculated results are ”negative humidities”
  - Down to ~-50° C the curve is very smooth and follows the shape of dry calibration curve. After ~-50° C there is more divergence in the data points and the curve starts clearly to go upwards at about -65° C

Example: humidity profile, sol 15 (preliminary)



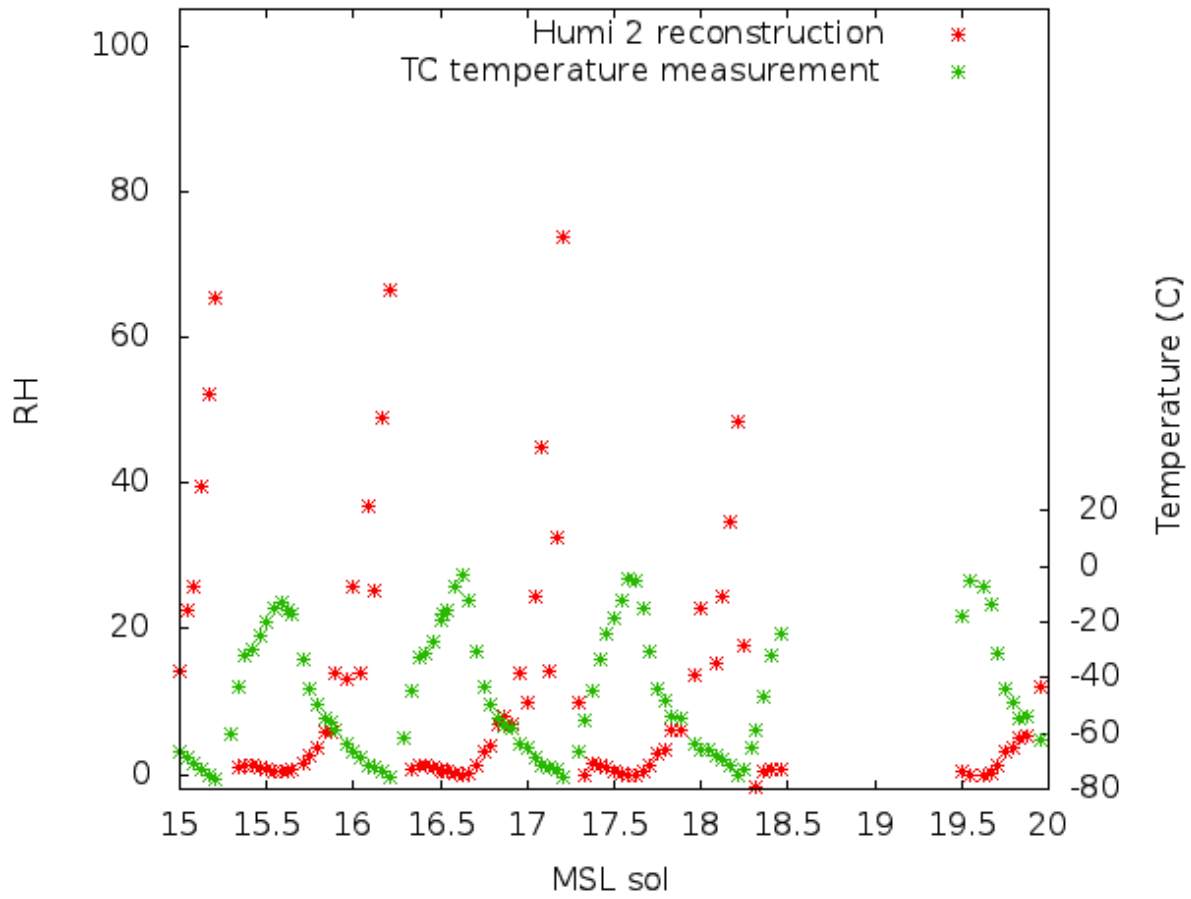


Highest humidity at M05:00 : ~65%RH relative to ice, T(HS) ~-76.8° C (T_Air ~-76° C)

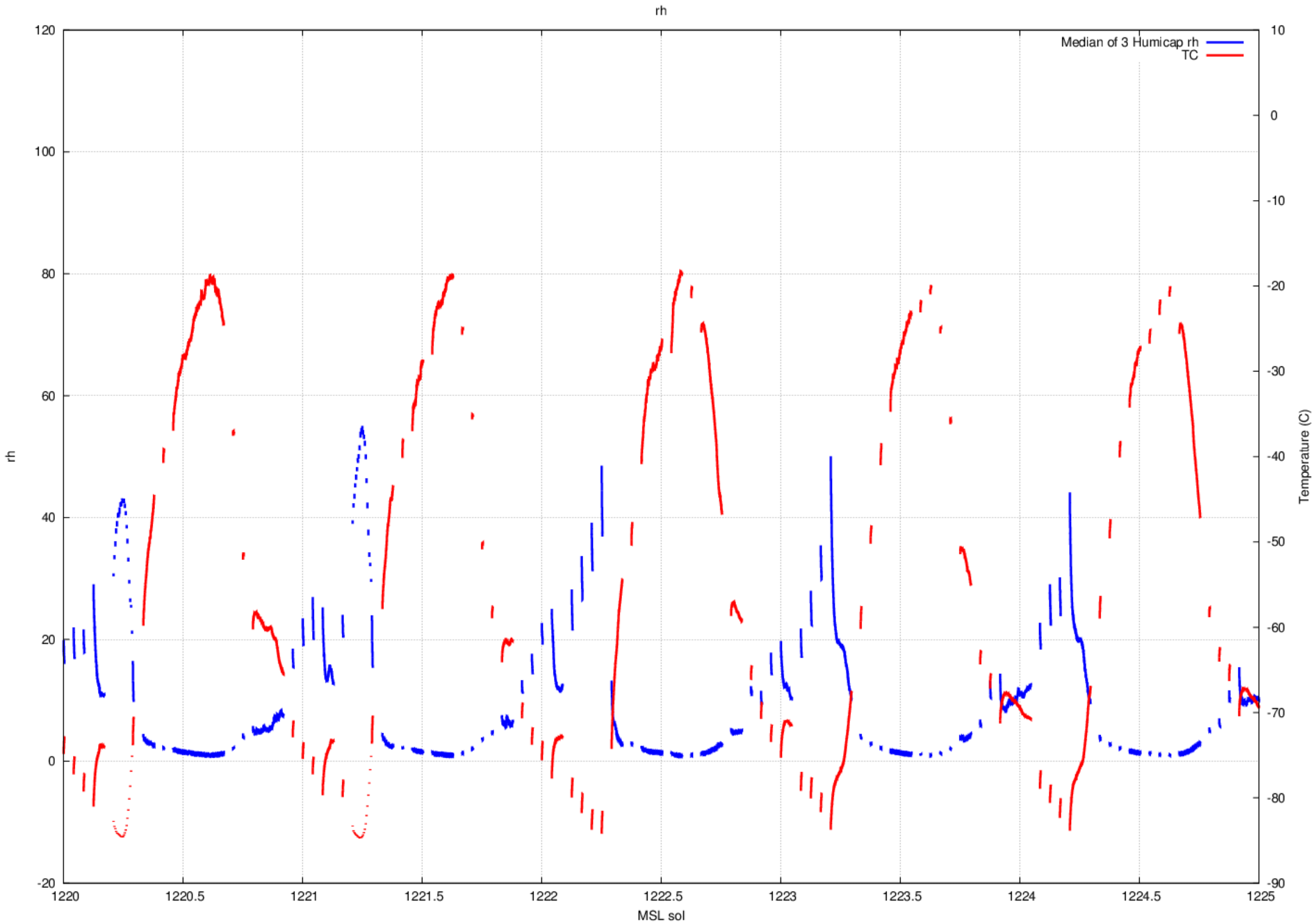
⇒Frostpoint ~-79° C, H_2O vmr ~80 ppm

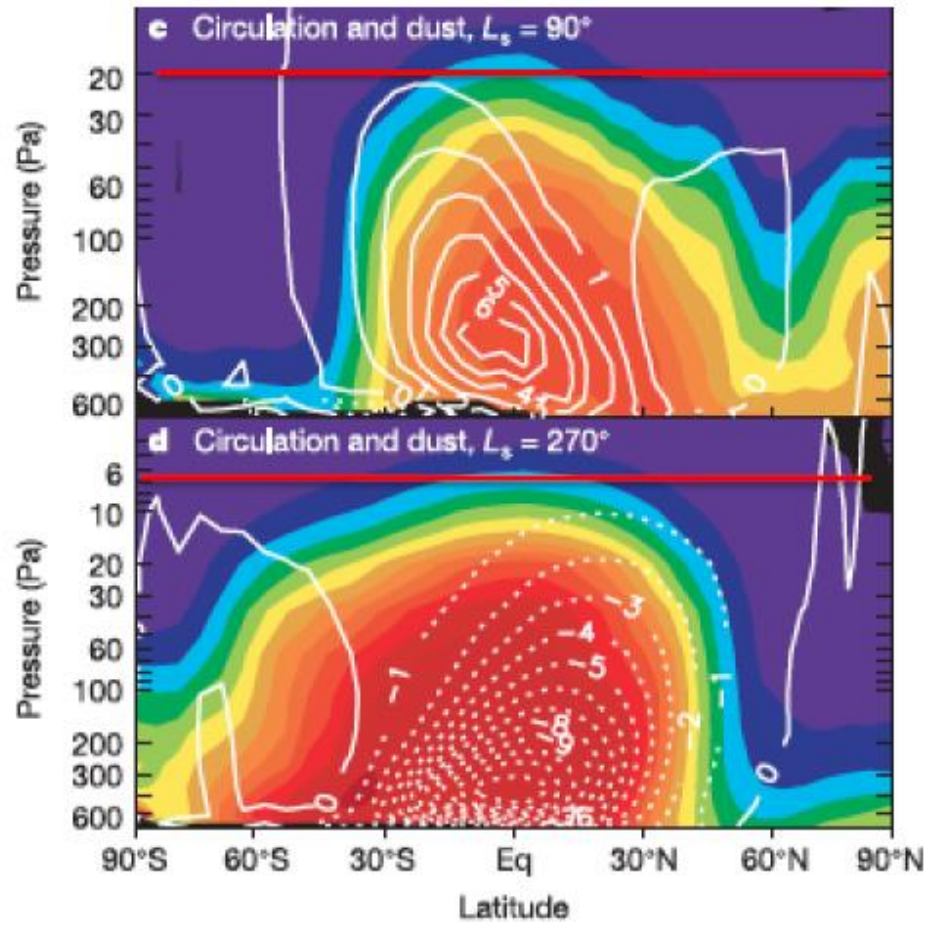
Preliminary values!

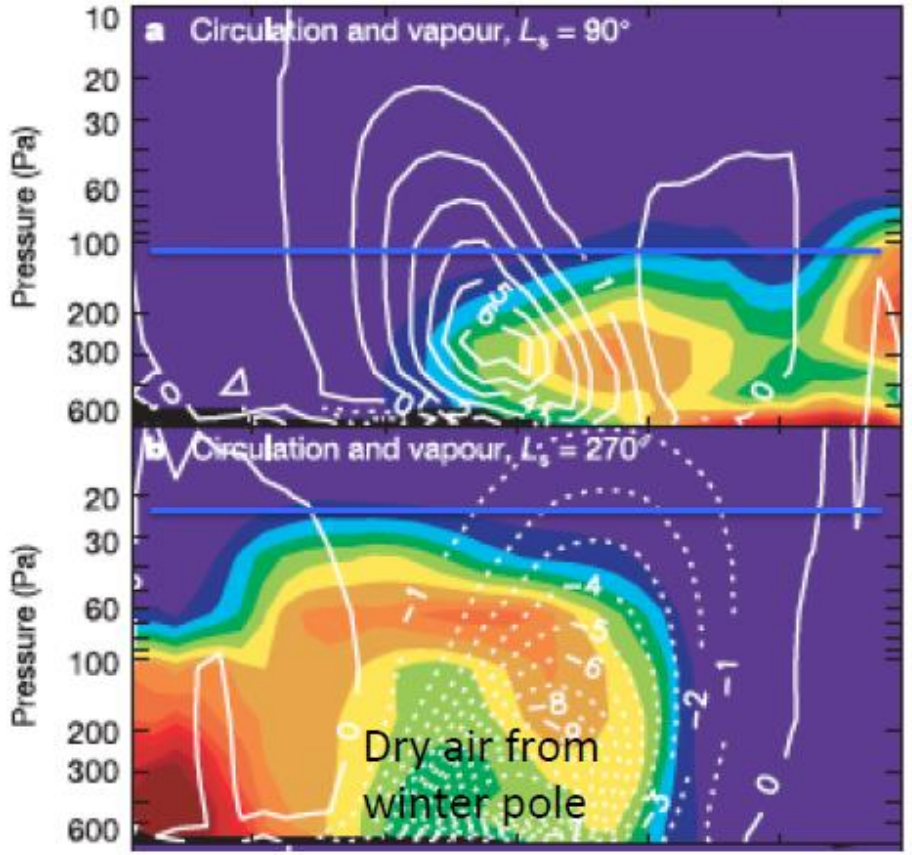
Humidity sols 15-19



Preliminary values!


rh
Median of 3 Humicap rh
TC
rh
Temperature (C)
MSL sol
120
100
80
60
40
20
0
-20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
1220
1220.5
1221
1221.5
1222
1222.5
1223
1223.5
1224
1224.5
1225





Richardson and Wilson, 2002