CALIBRATION OF NDSC MICROWAVE OZONE RADIOMETERS AT LAUDER, NEW ZEALAND AND MAUNA LOA, HAWAII

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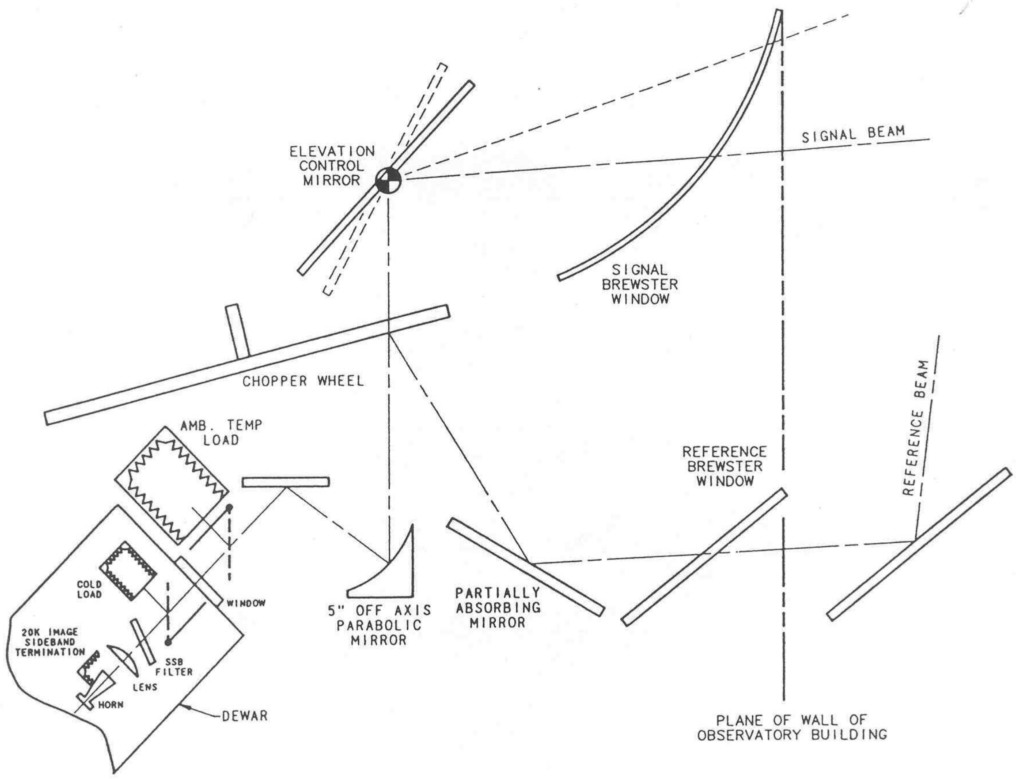
The discussion refers to the calibration of microwave ozone radiometers operated by a collaboration between the University of Massachusetts and NIWA. The instruments are located at Lauder, New Zealand and Mauna Loa, Hawaii.



QUASI-OPTICAL BANDPASS FILTER PASSES OZONE LINES AT 110.836 OR 109.559 GHZ, AND PROVIDES >20 DB IMAGE SIDEBAND REJECTION. IMAGE SIDEBAND TERMINATION IS AT ~20 K.

TWO BEAM SYSTEM. BEAMS ARE SWITCHED BY CHOPPER WHEEL.

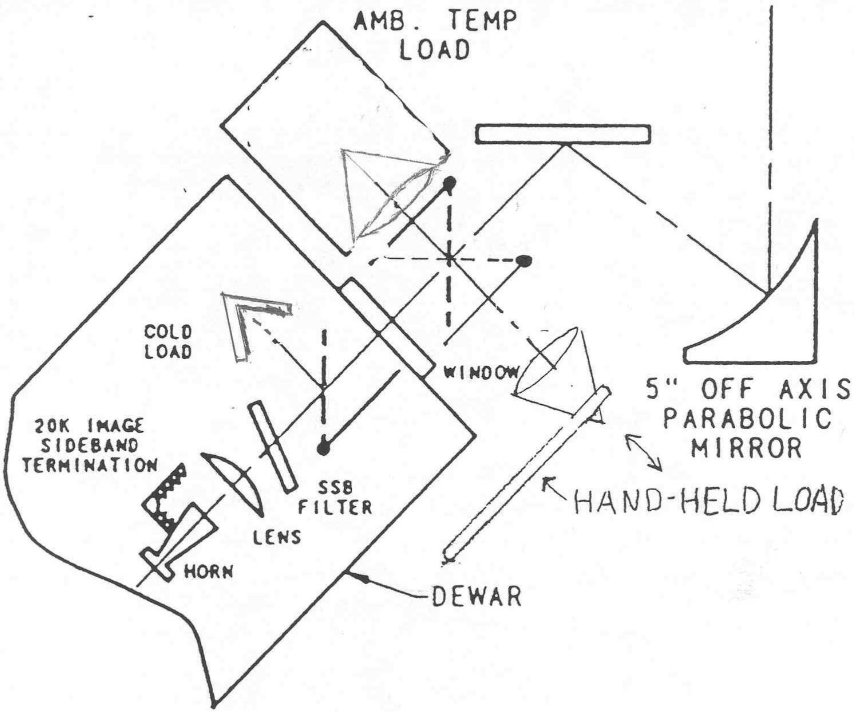
TEFLON WINDOWS AT BREWSTER'S ANGLE ISOLATE INSTRUMENT FROM WEATHER WITH MINIMAL LOSS AND REFLECTIVITY.

REFERENCE SIGNAL IS COMBINATION OF RADIATION FROM COLD SKY NEAR ZENITH AND 'GREY BODY' EMISSION FROM LOSSY DIELECTRIC IN BEAM PATH. BRIGHTNESS TEMPERATURE SEEN AT RECEIVER IS ~100-150 K.

SERVO ADJUSTS SIGNAL BEAM ELEVATION TO MINIMIZE DIFFERENCE BETWEEN SIGNAL AND REFERENCE CONTINUUM INTENSITY BY ADJUSTING SIGNAL BEAM ELEVATION.

HOURLY SKYDIP MEASUREMENTS OF TROPOSPHERIC CONTINUUM AT FIVE ANGLES BETWEEN 10 AND 25 DEG. PROVIDE RAW DATA FOR OPACITY DETERMINATION. BUILT IN, COMPUTER-CONTROLLED CALIBRATION LOADS ARE REFERENCES FOR SKYDIP MEASUREMENT.

BUILT IN LOADS ARE CALIBRATED EVERY FEW DAYS AGAINST HAND-HELD AMBIENT AND LN2 COOLED LOADS. THE LATTER ARE ALSO USED FOR THE RECEIVER NOISE TEMPERATURE MEASUREMENT.



CALIBRATION LOADS:

HAND-HELD COLD LOAD: A SEMICIRCLE OF ECCOSORB AN-73 IS FORMED INTO A CONE AND THE JOINT IS SEWN TOGETHER. THE CONE IS MOUNTED ON A WOODEN HANDLE.

TESTS SHOW COLD LOAD RADIOMETRIC TEMPERATURE IS STABLE FOR ~1 MINUTE AFTER REMOVAL FROM THE LN_2 BATH.

THE HAND-HELD AMBIENT LOAD IS A BLOCK OF "HILL AND VALLEY" ABSORBER.

THE BUILT-IN COLD LOAD CONSISTS OF TWO ALUMINUM PLATES COATED WITH CARBON-LOADED EPOXY TO A DEPTH OF ~4 MM MOUNTED ON THE REFRIGERATOR FIRST STAGE COLD PLATE IN THE FORM OF THE LETTER 'V'. A TEMPERATURE SENSOR IS EMBEDDED IN ONE OF THE PLATES. THE LOAD IS AT A RIGHT ANGLE TO THE NORMAL BEAM PATH, AND A SWITCHING MIRROR DIRECTS THE BEAM INTO THE CONE WHEN REQUIRED. THIS ARRANGEMENT IS INTENDED TO SHIELD THE LOAD FROM SOME OF THE INFARED RADIATION COMING IN THE DEWAR WINDOW.

THE BUILT-IN AMBIENT LOAD IS A CONE OF AN-73 ABSORBER IN A CAN. A SENSOR RECORDS TEMPERATURE IN THE CAN BEHIND THE CONE.

CALIBRATION:

THE RETRIEVAL RETURNS A PROFILE THAT MINIMIZES THE DIFFERENCES BETWEEN THE MEASURED AND MODELLED ANTENNA TEMPERATURES:

MEASURED NET ANTENNA TEMPERATURE:

$$T_{A\_MEAS}(\nu) = ((P_S(\nu) / P_R(\nu))^{\alpha(\nu)} - 1) * (T_{RX} + T_{REF}(\nu)) \quad (1)$$

RAW DATA SYSTEM TEMPERATURE

NET ANTENNA TEMPERATURE CALCULATED BY THE FORWARD MODEL:

$$T_{A\_MOD}(\nu) = \ \ *\exp(- \ _{W})*\{ T_{ST}(\nu, \ _{S})*\exp(- \ _{AS}) - T_{ST}(\nu, \ _{R})*\exp(- \ _{AR})*\exp(- \ _{D}) \} \quad (2)$$

SIGNAL REFERENCE

PARAMETERS:

P_S and P_R ARE RECORDED SIGNAL AND REFERENCE FILTERBANK DATA . THEY ARE CORRECTED FOR BIASES IN THE ABSENCE OF SIGNAL INPUT TO THE FILTERBANK USING DATA TAKEN OCCASIONALLY WITH THE SIGNAL FROM THE FRONT END DISCONNECTED. (CORRECTION ISN'T SHOWN IN EQ.)

(ν) DESCRIBES DEPARTURE FROM PERFECT LINEARITY OF INDIVIDUAL FILTER CHANNELS. OCCASIONALLY, DATA TAKEN AT SEVERAL SETTINGS OF A CALIBRATED ATTENUATOR IN THE IF ARE RECORDED AND A FITTING PROCEDURE USED TO DETERMINE .

T_{RX} ( ) IS THE RECEIVER NOISE TEMPERATURE. IT IS MEASURED OCCASIONALLY (EVERY 2-3 DAYS) USING THE HAND-HELD LOADS. THE LOADS ARE DELIBERATELY KEPT MOVING IN A SMALL CYCLICAL MOTION DURING THE MEASUREMENT TO SMEAR OUT STANDING WAVE ARTIFACTS.

(THE BUILT-IN LOADS ARE FIXED, AND THEIR STANDING WAVE ARTIFACTS ARE BIG ENOUGH TO SLIGHTLY DEGRADE THE MEASUREMENT IF USED FOR THE NOISE TEMPERATURE MEASUREMENT.)

T_{REF}( ): SEE NEXT VIEWGRAPH.

$$T_{A\_MEAS}(\nu) = ((P_S(\nu) / P_R(\nu))^{\alpha(\nu)} - 1) * (T_{RX} + T_{REF}(\nu)) \quad (1)$$

DISCUSSION OF $T_{REF}(\ )$:

$T_{REF}(\ )$ HAS SEVERAL COMPONENTS:

1) THE TROPOSPHERIC CONTINUUM EMISSION, WHICH IS CALCULATED AS A SCALAR USING AN ISOTHERMAL MODEL FROM THE TROPOSPHERIC OPACITY AND TEMPERATURE OF THE MODEL TROPOSPHERE. (DETAILS DISCUSSED LATER.)

2) A VECTOR CORRECTION TO THE TROPOSPHERIC EMISSION CALCULATION TO ACCOUNT FOR THE SLOPE IN THE WATER VAPOR CONTINUUM EMISSION AND THE SLOPE AND CURVATURE PRODUCED BY THE FAR WING OF THE 118 GHZ OXYGEN LINE.

3) AN ADDITIONAL VECTOR CORRECTION FOR THE CONTRIBUTION OF THE OZONE LINE IN THE REFERENCE BEAM. IT IS CALCULATED FROM A CLIMATOLOGICAL OZONE PROFILE, TAKING INTO ACCOUNT THE REFERENCE BEAM ELEVATION ANGLE AND THE OPACITIES OF THE TROPOSPHERE AND THE LOSSY DIELECTRIC SHEET.

PARAMETERS PASSED TO FORWARD MODEL:

$$T_{A\_MOD}(\nu) = \ *exp(- \ _{W})*\{ T_{ST}(\nu, \ _{S})*exp(- \ _{AS}) \ - \ T_{ST}(\nu, \ _{R})*exp(- \ _{AR})*exp(- \ _{D}) \} \qquad (2)$$

: BEAM EFFICIENCY, OBTAINED FROM BRIGHTNESS TEMPERATURE INCREASE WHEN COLD LOAD IS PLACED JUST INSIDE WINDOW INSTEAD OF NEAR RECEIVER INPUT. SIDELOBES ARE ASSUMED TO BE TERMINATED IN A ROOM TEMPERATURE BLACKBODY. (=98-99% IS TYPICAL FOR SYSTEM.)

$$T_{LOAD\text{-}AT\text{-}WINDOW} - T_{LOAD\text{-}NEAR\text{-}RX} = \ T_{PHYS\text{-}COLD} + (1 - \ )T_{PHYS\text{-}AMB} \qquad (3)$$

$_{W}$: WINDOW LOSS, OBTAINED FROM BRIGHTNESS TEMPERATURE OF COLD LOAD OUTSIDE WINDOW TO THAT INSIDE WINDOW. WINDOW MATERIAL TEMPERATURE IS TAKEN TO BE THE AVERAGE OF INDOOR AND OUTDOOR TEMPERATURE. ($_{W}$ = 0.01 NEPER IS TYPICAL FOR SYSTEM.)

BEAM ELEVATION ANGLES $_{S}$ AND $_{R}$: $_{S}$ IS OBTAINED FROM RECORDED ENCODER DATA, CORRECTED FOR INSTRUMENTAL OFFSET. MEASUREMENT OF THIS OFFSET WILL BE DISCUSSED LATER. $_{R}$ IS NOT CRITICAL AND IS ESTIMATED FROM GEOMETRY OF THE SYSTEM.

$_{AS}$, ETC.: $_{AS} = A_S* \ _{Z}$,
WHERE A_S 1/SIN($_{S}$) IS A GOOD APPROXIMATION.

$_{D}$: THE SERVO FORCES THE SIGNAL AND REFERENCE CONTINUUM EMISSION SEEN AT THE RECEIVER TO BE EQUAL. THE EQUALITY

$$T_{ATM}(1 - exp(- \ _{AS})) = T_{ATM}(1 - exp(- \ _{AR}))exp(- \ _{D}) + T_D(1 - exp(- \ _{D})) \qquad (5)$$

IS SOLVED FOR $_{D}$. T_{ATM} IS THE MODEL ATMOSPHERE TEMPERATURE, DISCUSSED BELOW. THIS EQUATION ASSUMES THAT THE ABSORPTION COEFFICIENT IS UNIFORM AT ALL ELEVATION ANGLES. ANOMALOUS $_{D}$ VALUES CAN SERVE AS A DIAGNOSTIC FOR A NON-UNIFORM SKY.

TROPOSPHERIC OPACITY DETERMINATION:

THE TROPOSPHERIC OPACITY, , CAN BE ANALYTICALLY CALCULATED FROM THE MEASURED BRIGHTNESS TEMPERATURE T_B IF THE TROPOSPHERE IS ASSUMED TO BE ISOTHERMAL:

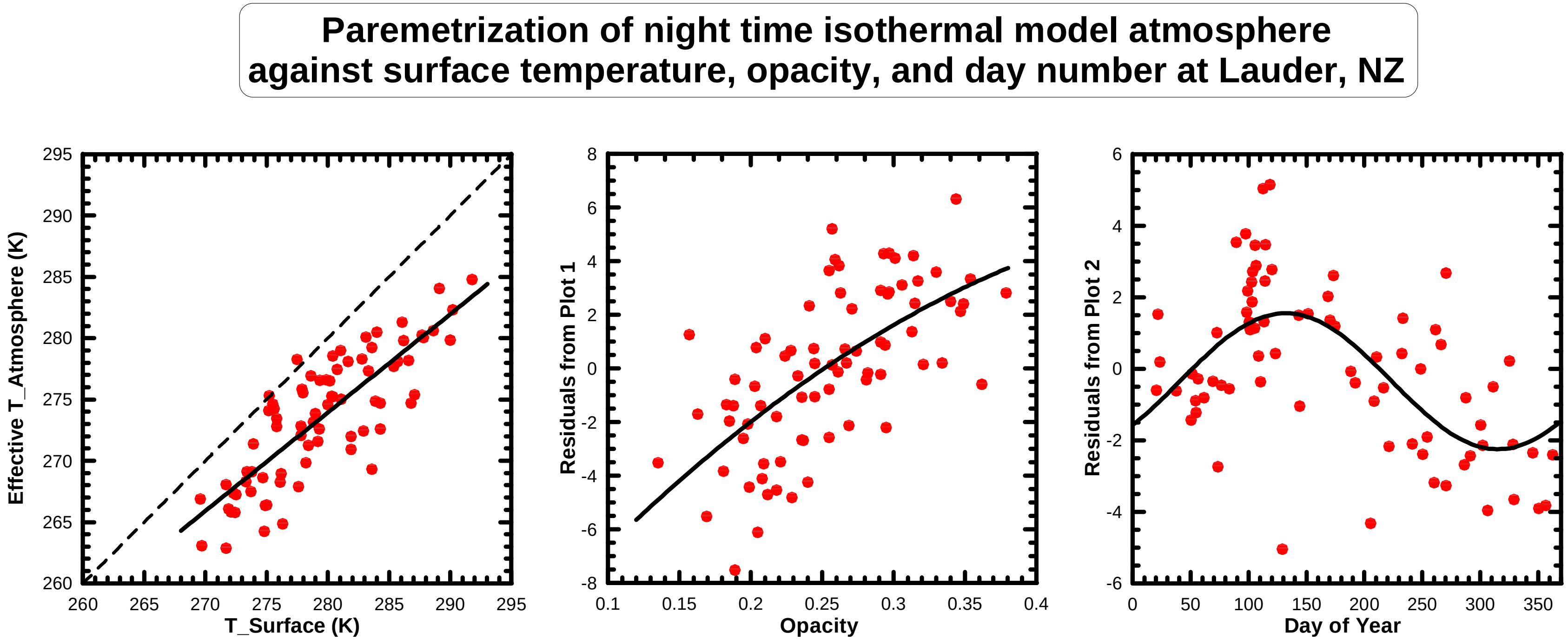
$$= \ln\{(T_{ATM} - T_B)/T_{ATM} \quad \} \qquad (6)$$

(THE COSMIC BACKGROUND RADIATION IS NEGLECTED IN THIS DISCUSSION.)

TO FIND THE CLIMATOLOGICALLY OPTIMUM VALUE OF T_{ATM} TO USE WITH EACH OBSERVATION, WE HAVE USED TEMPERATURE AND HUMIDITY PROFILES FROM SETS OF RADIOSONDE PROFILES. USING LIEBE'S MODEL FOR THE ABSORPTION COEFFICIENT VS. FREQUENCY, TEMPERATURE, PRESSURE, AND HUMIDITY, WE HAVE DONE A RADIATIVE TRANSFER CALCULATION FOR T_B AND HAVE INTEGRATED THE ABSORPTION COEFFICIENT TO OBTAIN THE CORRESPONDING FOR EACH FLIGHT. WE SOLVE (6) FOR T_{ATM}, INSERT THE MODELLED T_B AND TO GET THE OPTIMUM VALUE OF T_{ATM} TO USE FOR THE ATMOSPHERIC CONDITIONS ASSOCIATED WITH EACH FLIGHT.

WE THEN PARAMETRIZE $T_{ATM} = T_{OUT} - T_{ATM}$ AGAINST VARIABLES WITH KNOWN VALUES AT THE TIME OF EACH MEASUREMENT, SUCH AS THE OUTSIDE TEMPERATURE T_{OUT} AND THE DAY NUMBER (TO ACCOUNT FOR SEASONAL EFFECTS). INCLUDING AN ESTIMATE OF THE TROPOSPHERIC OPACITY FURTHER REDUCES THE RMS OF THE RESIDUALS.

THE PLOTS ON THE FOLLOWING PAGE SHOWS THAT T_{ATM} IS LESS THAN T_{OUT}, AS ONE WOULD EXPECT GIVEN THAT TEMPERATURE DECREASES WITH HEIGHT IN THE TROPOSPHERE. HOWEVER, THE DIFFERENCE, T_{ATM}, ALSO DEPENDS ON T_{OUT} (SHOWN AS T_Surface) ON THE PLOT, THE SEASON (DAY OF YEAR) AND THE TROPOSPHERIC OPACITY. (AN INITIAL ESTIMATE OF THE OPACITY CALCULATED USING A CONSTANT T_{ATM} IS USED ALONG WITH T_{OUT} AND THE DAYNUMBER TO OBTAIN A BEST ESTIMATE OF THE OPACITY FOR THE PROCESSING OF A GIVEN OBSERVATION.



Paremetrization of night time isothermal model atmosphere
against surface temperature, opacity, and day number at Lauder, NZ
Effective T_Atmosphere (K)
T_Surface (K)
260
265
270
275
280
285
290
295
Residuals from Plot 1
Opacity
0.1
0.15
0.2
0.25
0.3
0.35
0.4
-8
-6
-4
-2
0
2
4
6
8
Residuals from Plot 2
Day of Year
0
50
100
150
200
250
300
350
-6
-4
-2
0
2
4
6

ELEVATION ANGLE ENCODER CALIBRATION:

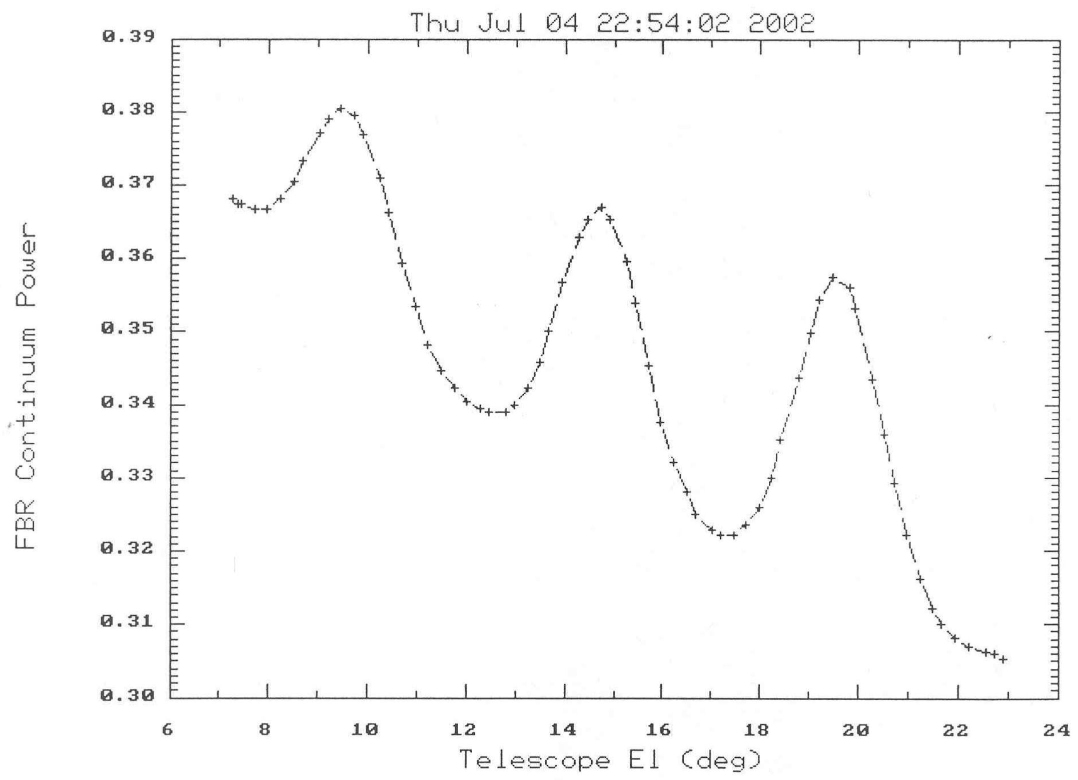
ACCURATE ELEVATION ANGLE MEASUREMENTS ARE CRITICAL. FOR THIS EXPERIMENT THE SENSITIVITY OF THE RETRIEVED OZONE VALUES TO ELEVATION ANGLE ERROR IS ~10% PER DEGREE.

THE INSTRUMENT CAN SWEEP THE SIGNAL BEAM IN ELEVATION AND RECORD THE CONTINUUM INTENSITY. THIS FEATURE IS USED WITH THE SUN OR A POLE-MOUNTED CALIBRATION TARGET AS THE SOURCE FOR ENCODER CALIBRATION.

WHEN THE SUN IS USED, AN EPHEMERIS CALCULATION GIVES THE TRUE SOLAR ELEVATION ANGLE FOR EACH DATA POINT.

THE POSITION OF THE CALIBRATION TARGET RELATIVE TO THE ELEVATION MIRROR SHAFT CENTERLINE IS ESTABLISHED USING SURVEYOR'S INSTRUMENTS. EXPERIENCE SUGGESTS THAT SURVEYS CAN ESTABLISH THE TRUE TARGET ANGLE TO BETTER THAN 0.1 .

THE OBSERVED INTENSITY FROM A SIGNAL BEAM ELEVATION SWEEP PAST THREE WOODEN CROSSBARS MOUNTED ON A POLE IS PLOTTED AGAINST ELEVATION READOUT ANGLE BELOW.



AT LAUDER IN 1996, WE FOUND THAT THE ELEVATION ANGLES OF THE CALIBRATION TARGETS AS MEASURED IN 1992 HAD BEEN INVALIDATED BECAUSE THE INSTRUMENT BUILDING OR CALIBRATION POLE FOUNDATION PAD HAD SETTLED IN THE MEANTIME, NECESSITATING AN ALTERNATE MEANS OF CALIBRATION.

THE APPROACH WE USED WAS TO FIT THE SKYDIP DATA WITH BOTH ZENITH OPTICAL DEPTH AND ELEVATION ANGLE OFFSET AS FREE PARAMETERS. (NORMALLY AN ELEVATION ANGLE OFFSET IS FURNISHED BASED ON AN ELEVATION SWEEP PAST TARGETS AT KNOWN ELEVATION ANGLES AS SHOWN ON THE PREVIOUS VIEWGRAPH.)

THE PLOT ON THE FOLLOWING PAGE SHOWS ELEVATION ANGLE OFFSET DATA OBTAINED BY THIS TECHNIQUE FOR THE 1992-1996 PERIOD, SUGGESTING SIGNIFICANT SHIFTS AND DRIFTS IN THE OFFSET.

BEGINNING IN 1996, THE TRUE ELEVATION ANGLES OF THE CALIBRATION TARGETS WERE RE-MEASURED EVERY TIME AN ELEVATION ANGLE CALIBRATION WAS PERFORMED.

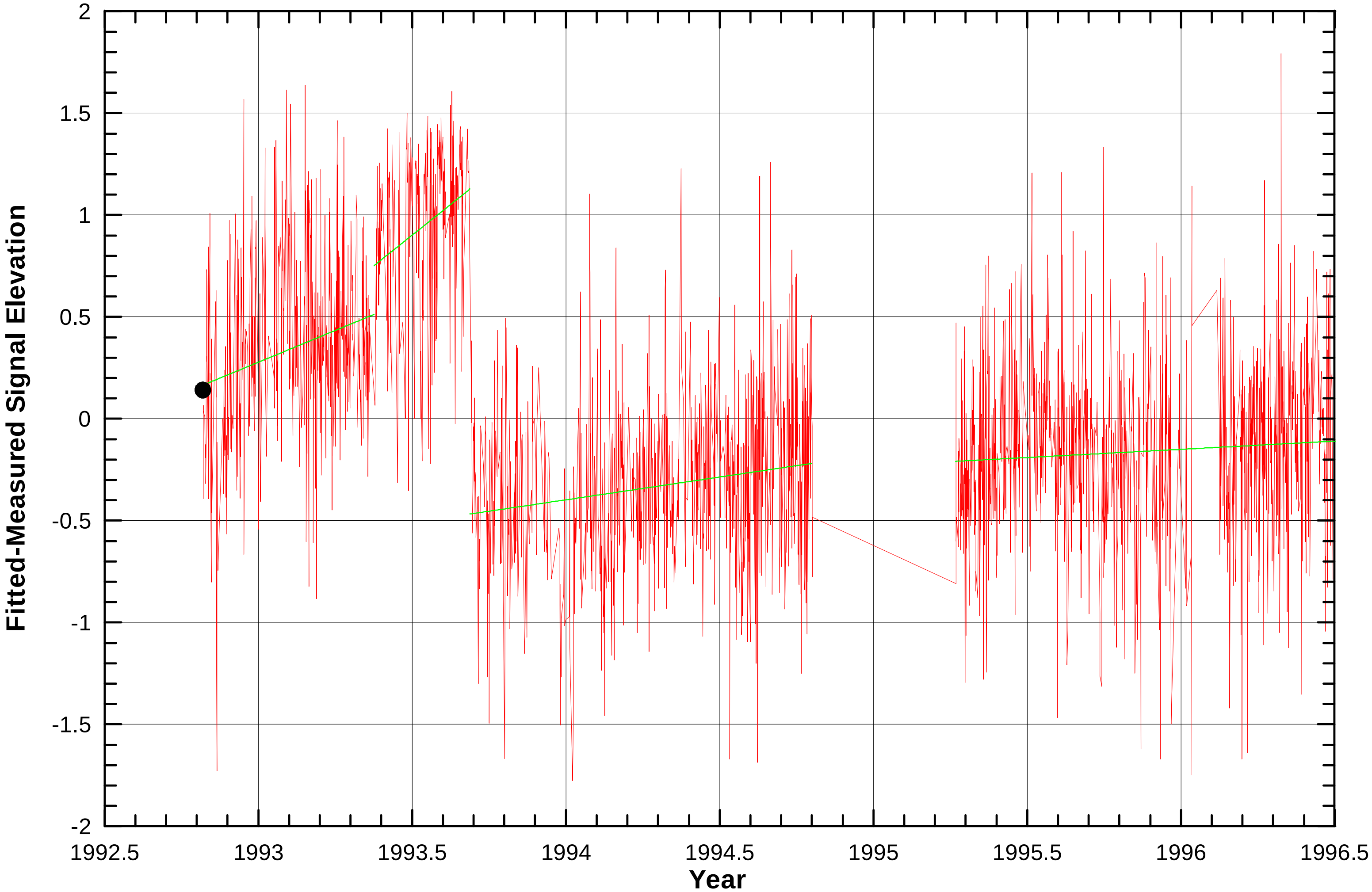
THE SECOND FOLLOWING PLOT SHOWS THE ELEVATION ANGLE OFFSETS DERIVED FROM ELEVATION SWEEPS PAST THE TARGETS FOR THE PERIOD 1996.5-2003. ALSO SHOWN (BLUE DOTS) ARE SWEEPS DONE USING THE SUN AS A CALIBRATION TARGET. (SOLAR SWEEPS CAN BE DONE WITHOUT DISTURBING THE INSTRUMENT AROUND THE TIMES OF THE VERNAL AND AUTUMNAL EQUINOXES.)

THE SECOND PLOT ALSO SHOWS OFFSET DATA DERIVED FROM THE SIMULTANEOUS OPTICAL DEPTH AND OFFSET FIT, AND A 50 POINT RUNNING AVERAGE OF THAT DATA.

THE GOOD AGREEMENT BETWEEN THE SWEEP AND SKYDIP DATA SHOWS THAT THE DRIFTS AND SHIFTS IN THE PRE-1996 DATA ARE REAL, AND THAT AN ACCURACY OF THE ORDER OF 0.1 DEG. CAN BE OBTAINED FROM THE SMOOTHED SKYDIP DATA.

PLOT OF DELTA ELEVATION CORRECTIONS AT LAUDER
OBTAINED BY RUNNING CALIB IN 'GDDEL' TRUE AND FALSE MODES

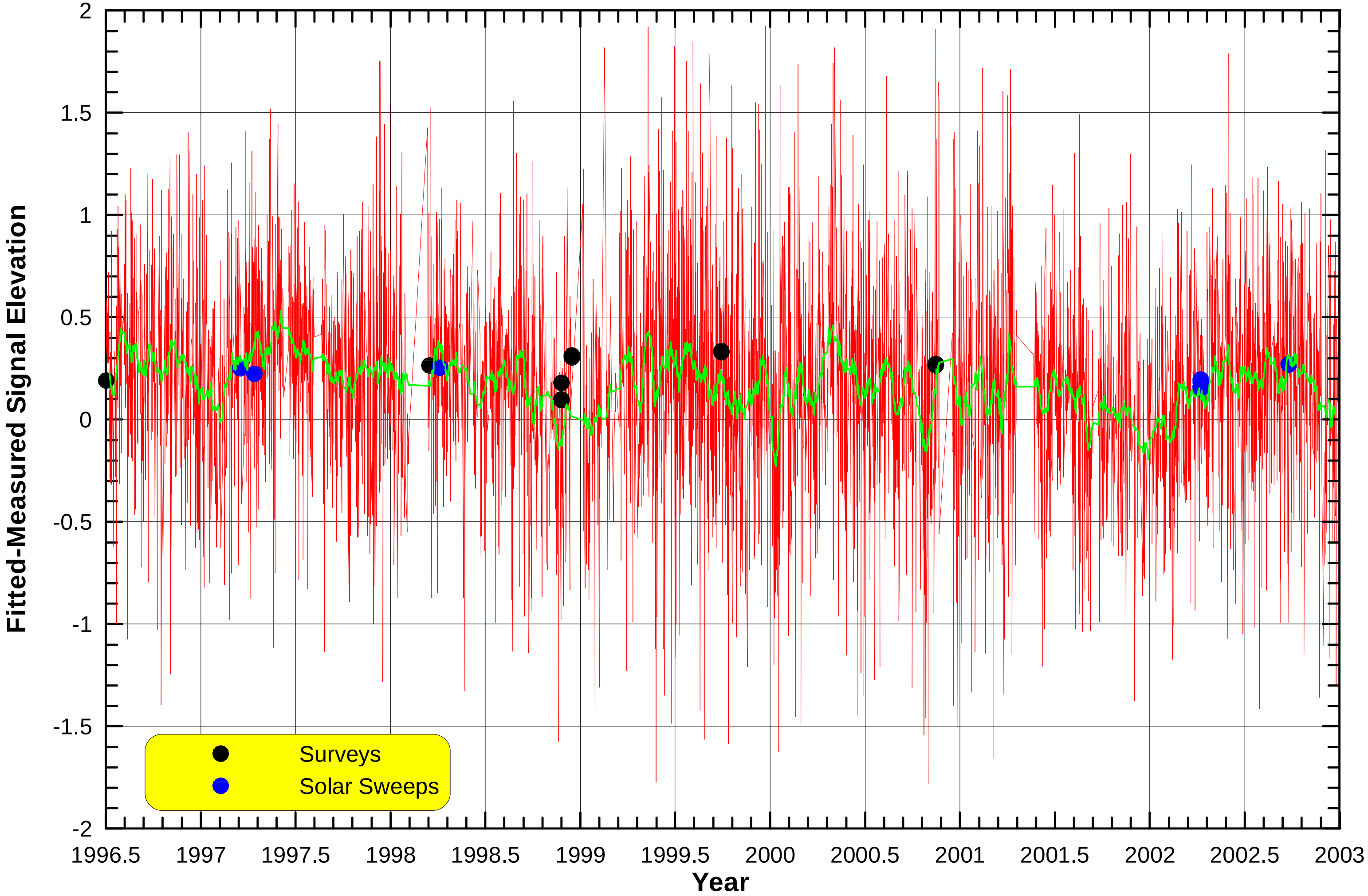
(also added is a survey measurement)



Y = 0.62348 * X - 1242.32   Y = 1.20424 * X - 2399.75   Y = 0.22363 * X - 446.32   Y = 0.080517 * X - 160.86

PLOT OF DELTA ELEVATION CORRECTIONS AT LAUDER OBTAINED BY RUNNING CALIB IN 'GDDEL' TRUE AND FALSE MODES

(also added are measurements from Solar Sweeps and Surveys)

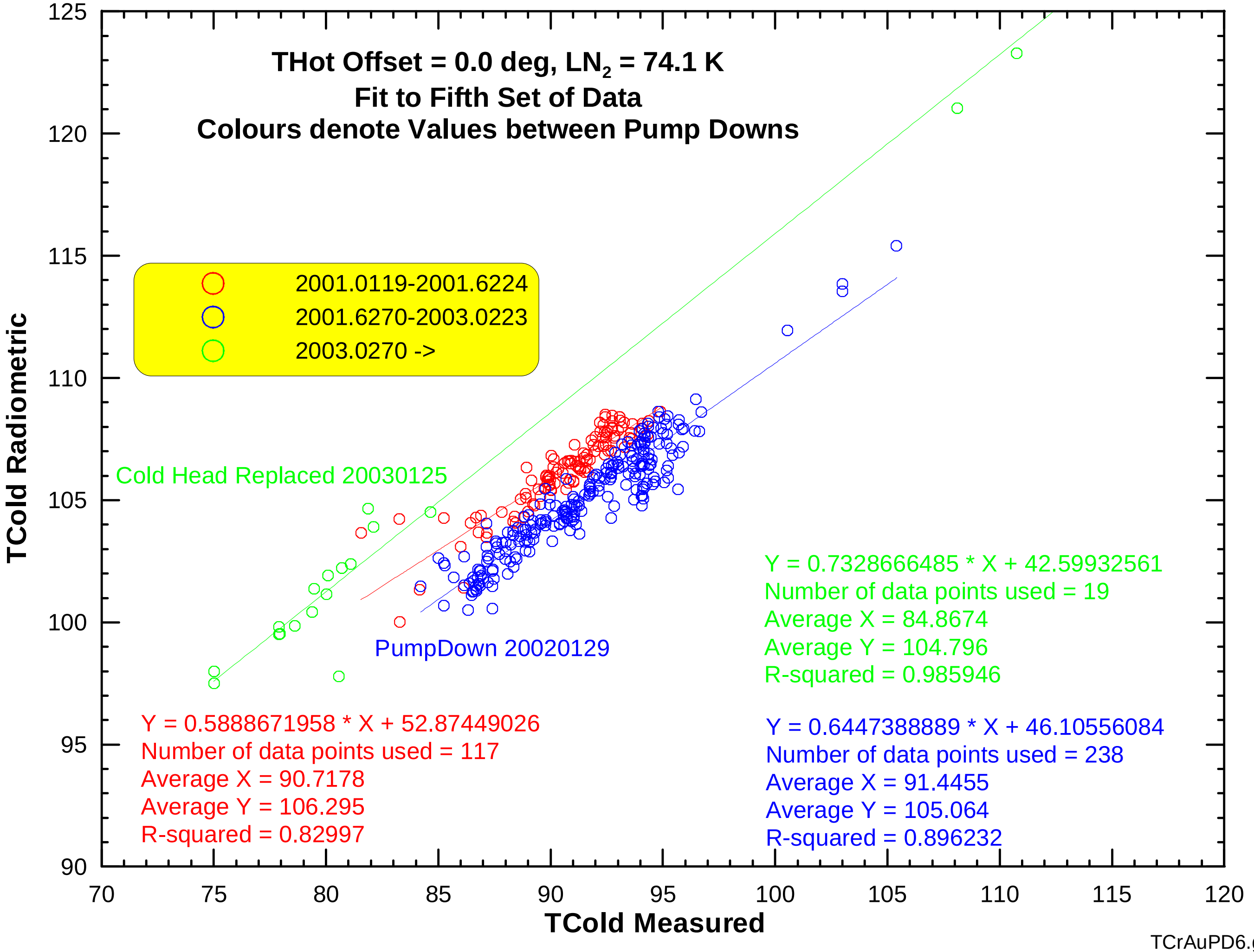


Apparent shift in DelEl Values between days 180 and 184 of 1996 (1996.5)

IT IS CRITICAL THAT THE BRIGHTNESS TEMPERATURES OF THE CALIBRATION LOADS USED IN THE SKYDIP MEASUREMENTS BE ACCURATELY KNOWN. TO INSURE THIS, WE MEASURE THE BRIGHTNESS TEMPERATURE OF THE INTERNAL COLD LOAD (WHICH IS USED IN THE AUTOMATIC SKYDIP MEASUREMENTS) AGAINST THE LN_2-SOAKED, HAND-HELD LOADS EVERY FEW DAYS.

PLOTS OF THE INTERNAL COLD LOAD BRIGHTNESS TEMPERATURE VS. ITS READOUT PHYSICAL TEMPERATURE MAY SHOW CHANGES IN SLOPE AND OFFSET FROM TIME TO TIME FOR REASONS NOT PRESENTLY UNDERSTOOD. THIS PROBLEM IS WORST AT MAUNA LOA, WHERE CHANGES TYPICALLY OCCUR FOLLOWING FULL OR PARTIAL WARMUPS OF THE CRYOGENIC SYSTEM. THE FOLLOWING PLOT SHOWS SEVERAL EXAMPLES FROM MAUNA LOA DATA. AT LAUDER, A NOTICEABLE SHIFT WAS SEEN ONLY FOLLOWING DISASSEMBLY OF THE RECEIVER FOR REPAIRS.

TCrAuto Corrections at Mauna Loa



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