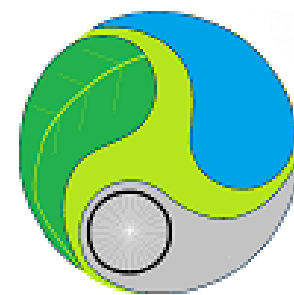


Simulation and Validation of Seasonal Soil Temperature Variations Using COMSOL Multiphysics

Larry John Matel, P.E.



Green Streets Infrastructure LLC

Acknowledgements

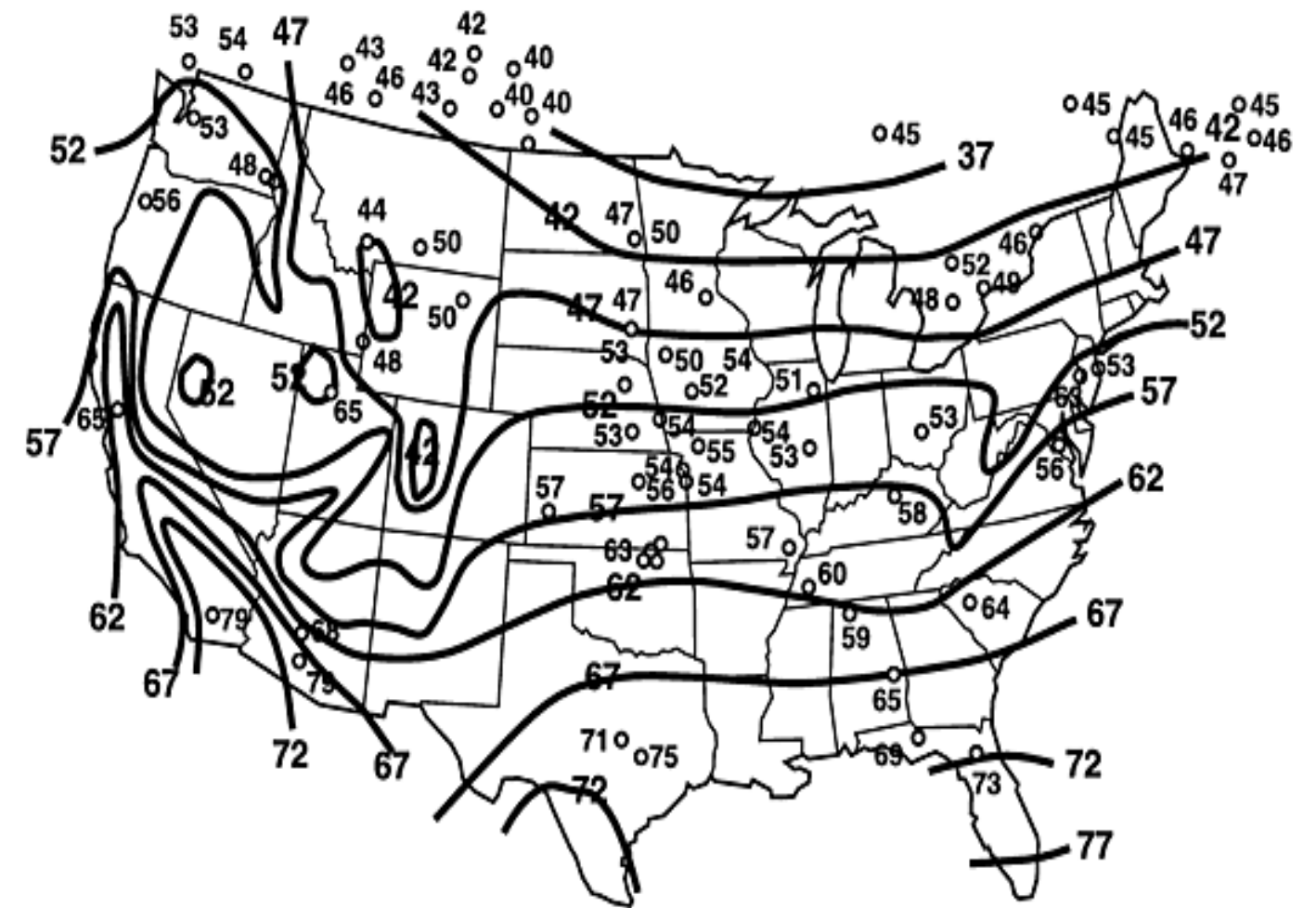
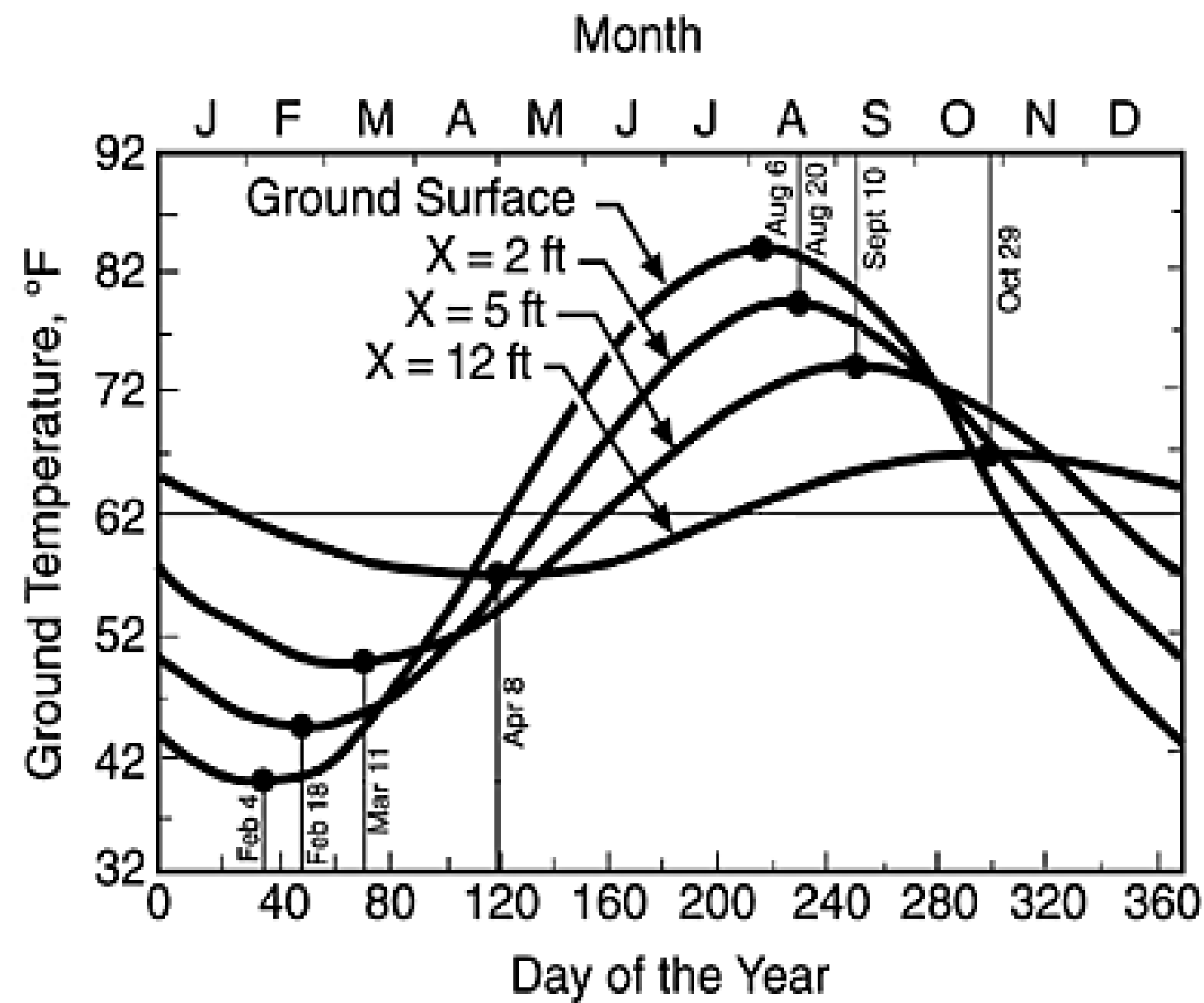
- US Environmental Protection Agency
- Washington Department of Ecology
- City of Bremerton Washington



Interested Communities

- Civil/Environmental Engineers
- Soil Scientists
- Agronomists





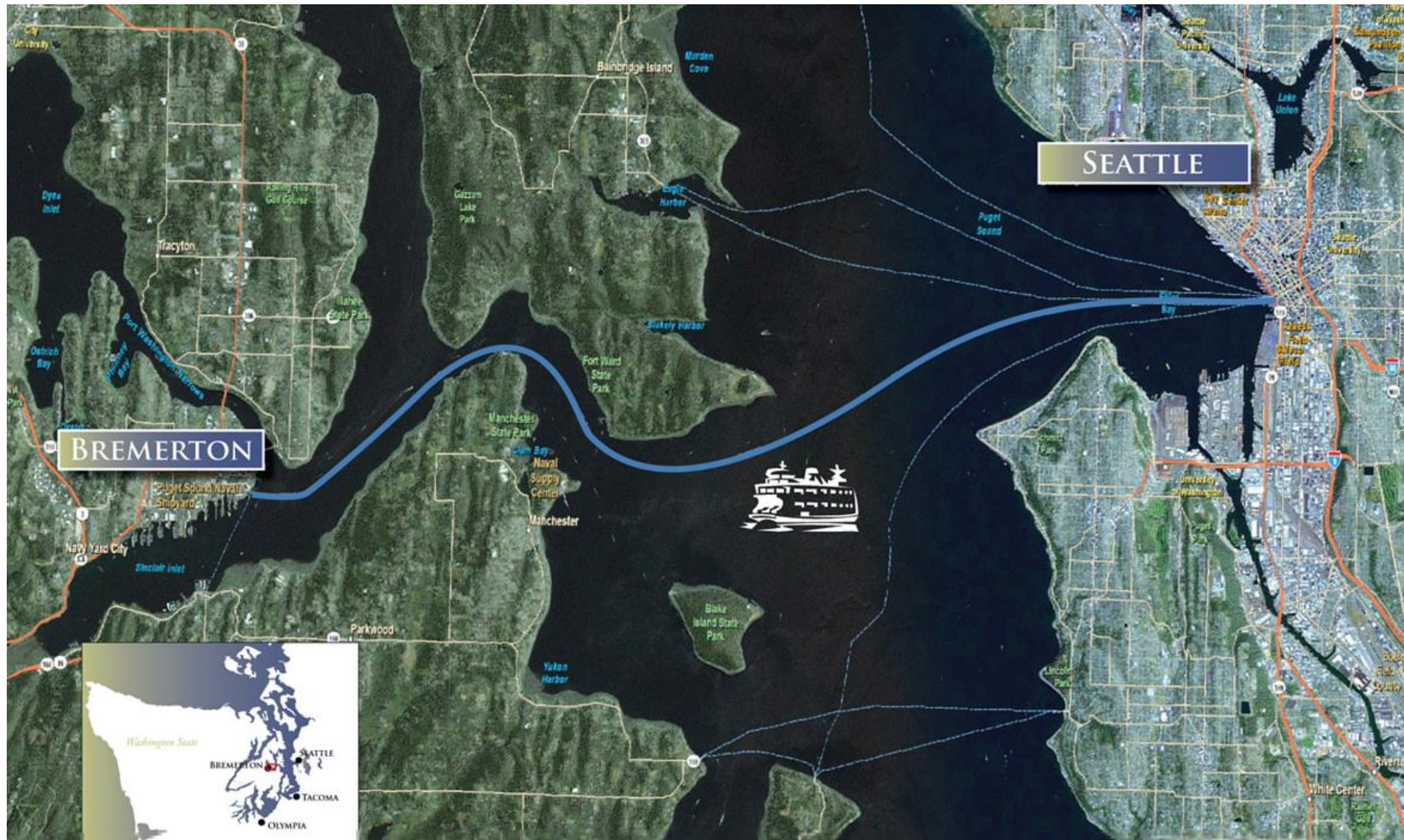
Source: West Virginia Tech

$$T = T_0 + A \sin (wt)$$



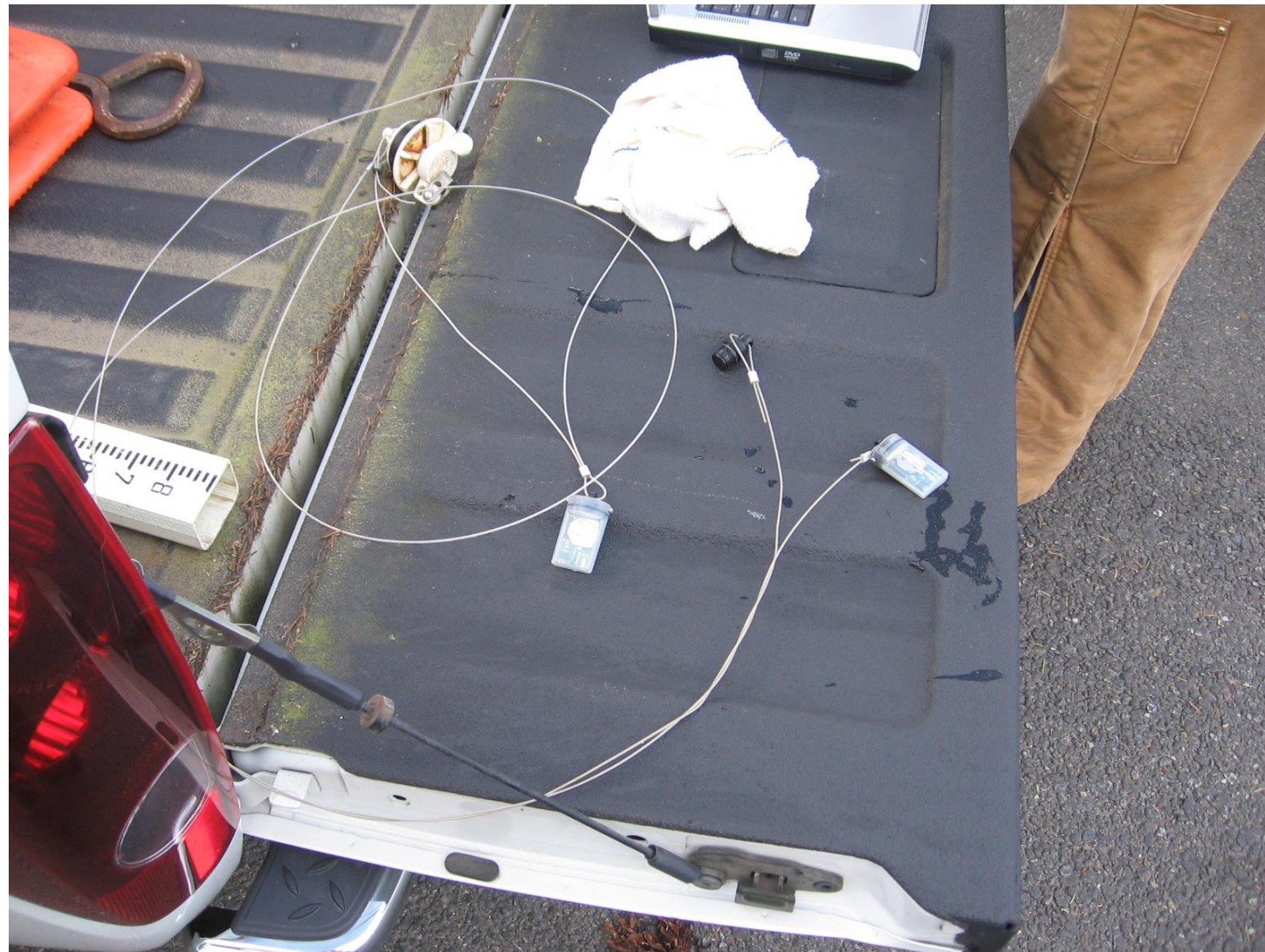
Green Streets Infrastructure LLC

Geographic Setting

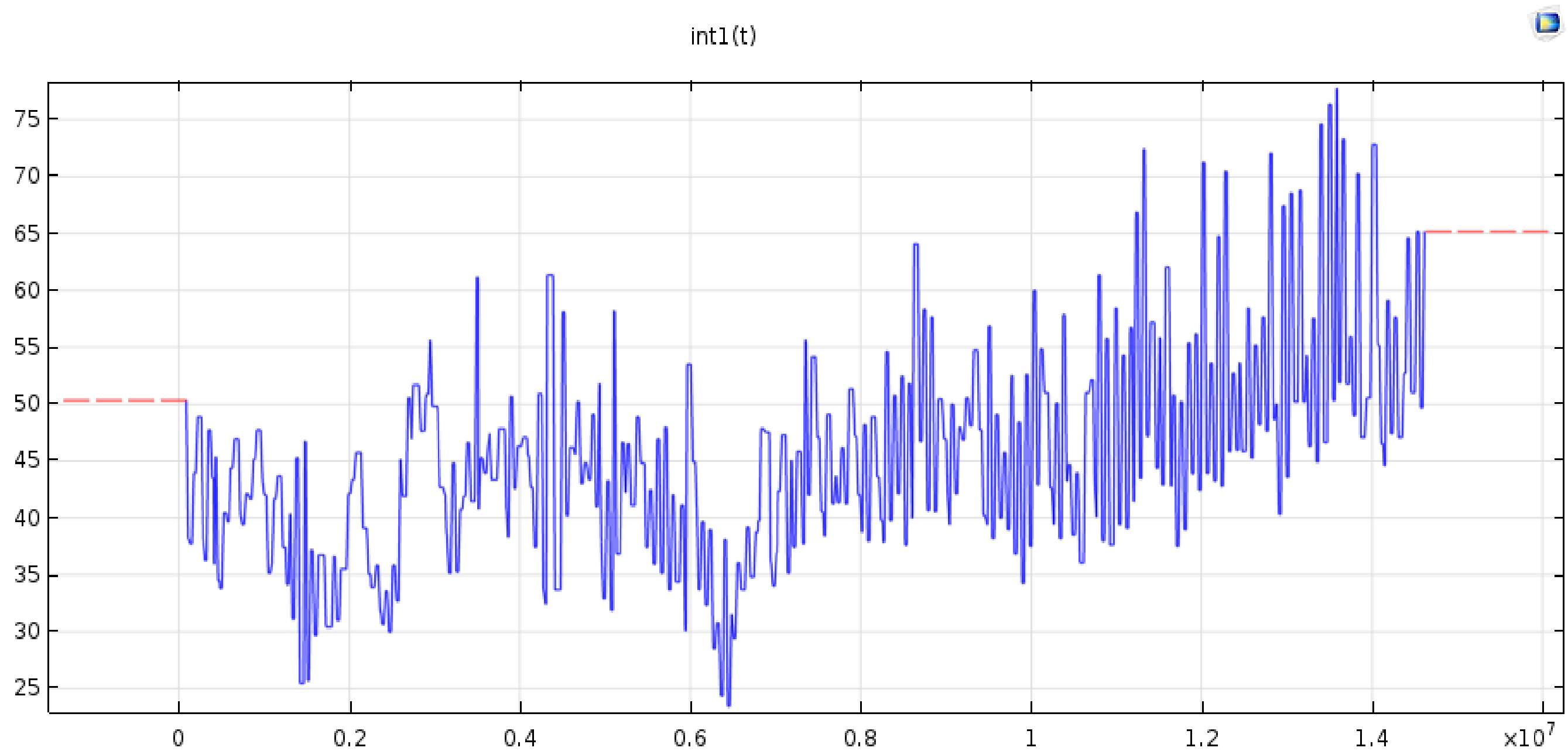


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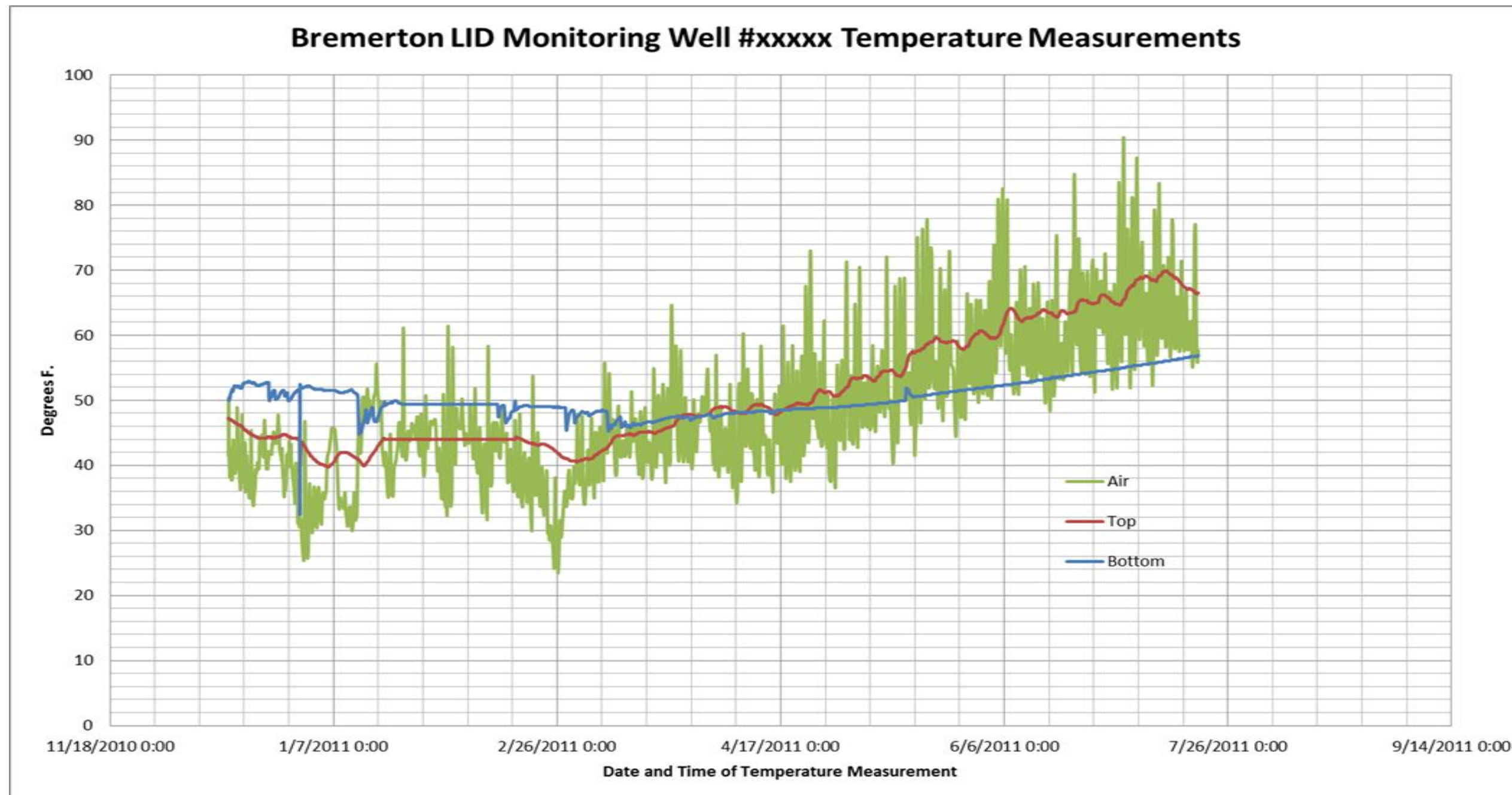
Data Collection



Ambient Air Temperature Variations – Dec. 2010 - July 2011



Monitoring Well Temperature Variations –Dec. 2010 - July 2011



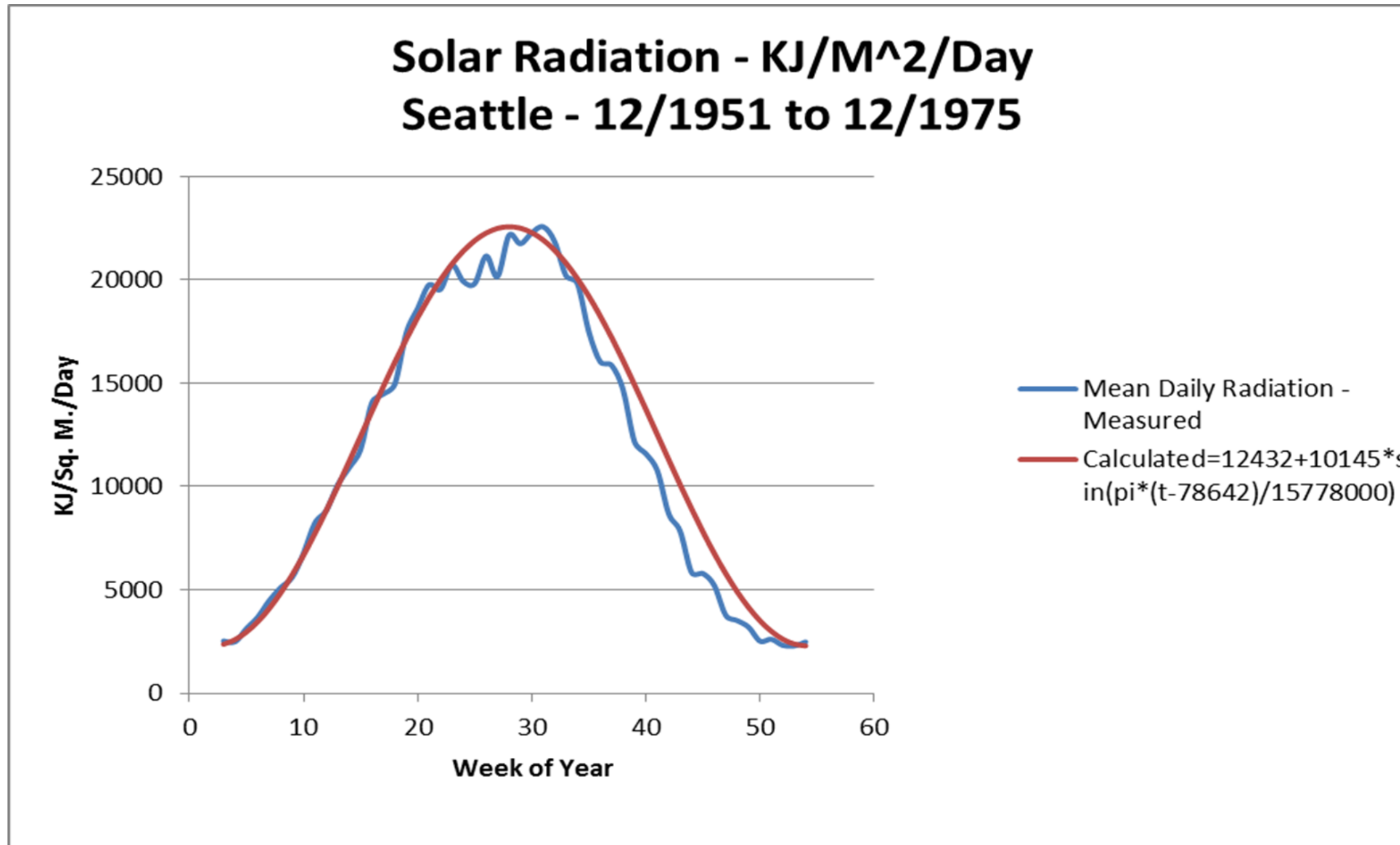
SOLAR RADIATION IN KILOJOULES PER SQUARE METER PER DAY BY CLIMATIC WEEK AT SEATTLE-TACOMA, WA.
(STATION NO. 24233) DEC, 1951 - DEC, 1975

| CLIMATIC WEEK | NUMBER OBS | MINIMUM RADIATION | MAXIMUM RADIATION | MEAN RADIATION | STD OF MEAN | PROBABILITY IN PERCENT OF RECEIVING AT LEAST THE INDICATED AMOUNT | | | | | | | | | |
|---------------|------------|-------------------|-------------------|----------------|-------------|-------------------------------------------------------------------|-------|-------|-------|-------------|-------|-------|-------|-------|--|
| | | | | | | 2Q | 8Q | 7Q | 6Q | 5Q (MEDIAN) | 4Q | 3Q | 2Q | 1Q | |
| 03/01 - 03/07 | 168 | 1297 | 14512 | 8230 | 283 | 3229 | 4448 | 5588 | 6709 | 8320 | 8963 | 10574 | 12409 | 13402 | |
| 03/08 - 03/14 | 168 | 1728 | 15829 | 8848 | 305 | 3493 | 5006 | 6019 | 6961 | 8545 | 9725 | 11550 | 13222 | 14516 | |
| 03/15 - 03/21 | 168 | 2216 | 19133 | 10087 | 327 | 4346 | 5611 | 6962 | 8611 | 10319 | 11345 | 12329 | 14111 | 16080 | |
| 03/22 - 03/28 | 168 | 1972 | 19135 | 10911 | 360 | 4925 | 6033 | 7226 | 8701 | 10872 | 12720 | 14078 | 15797 | 17207 | |
| 03/29 - 04/04 | 168 | 1810 | 20828 | 11794 | 398 | 5282 | 6792 | 8205 | 8994 | 10697 | 12681 | 15479 | 17757 | 19148 | |
| 04/05 - 04/11 | 168 | 3557 | 21983 | 14065 | 411 | 6611 | 8585 | 10460 | 12093 | 13964 | 16817 | 18324 | 19593 | 20666 | |
| 04/12 - 04/18 | 168 | 4206 | 24232 | 14481 | 424 | 6832 | 8920 | 10456 | 12422 | 14666 | 16386 | 17785 | 20220 | 21821 | |
| 04/19 - 04/25 | 168 | 2784 | 24798 | 14956 | 435 | 7667 | 9432 | 11736 | 13092 | 14183 | 17119 | 18692 | 20739 | 22830 | |
| 04/26 - 05/02 | 168 | 4206 | 26317 | 17422 | 449 | 9004 | 11376 | 13879 | 16043 | 17703 | 19931 | 21512 | 23204 | 24595 | |
| 05/03 - 05/09 | 168 | 3297 | 27603 | 18613 | 498 | 8542 | 11449 | 15243 | 17314 | 19985 | 21584 | 23722 | 25124 | 25954 | |
| 05/10 - 05/16 | 168 | 3571 | 27970 | 19762 | 506 | 9329 | 13500 | 15701 | 19197 | 21248 | 22903 | 25059 | 26173 | 26947 | |
| 05/17 - 05/23 | 168 | 3156 | 30920 | 19543 | 506 | 9989 | 12750 | 15283 | 17763 | 19792 | 21510 | 24843 | 26541 | 27726 | |
| 05/24 - 05/30 | 168 | 3740 | 31161 | 20719 | 521 | 11318 | 13801 | 17779 | 19218 | 21394 | 23485 | 26010 | 27409 | 28364 | |
| 05/31 - 06/06 | 168 | 2762 | 29736 | 19928 | 596 | 8369 | 11531 | 14817 | 17258 | 21005 | 24158 | 26706 | 28129 | 28991 | |
| 06/07 - 06/13 | 168 | 3876 | 31389 | 19824 | 545 | 9221 | 13592 | 16281 | 17882 | 19648 | 21745 | 23905 | 27426 | 29509 | |
| 06/14 - 06/20 | 168 | 5732 | 31999 | 21163 | 544 | 10992 | 14043 | 16614 | 20093 | 21362 | 24071 | 26448 | 28624 | 29714 | |
| 06/21 - 06/27 | 168 | 6036 | 30930 | 20166 | 553 | 9658 | 12873 | 15362 | 18036 | 20373 | 23227 | 25686 | 27231 | 29459 | |
| 06/28 - 07/04 | 168 | 3777 | 31089 | 22162 | 533 | 12242 | 15389 | 18556 | 21021 | 23379 | 25797 | 27619 | 29239 | 29610 | |
| 07/05 - 07/11 | 168 | 6441 | 30205 | 21754 | 536 | 10693 | 14297 | 17826 | 20939 | 22739 | 25070 | 27546 | 29022 | 29483 | |
| 07/12 - 07/18 | 168 | 6173 | 30349 | 23278 | 480 | 13742 | 18002 | 20866 | 23207 | 25448 | 26838 | 28379 | 28806 | 29062 | |
| 07/19 - 07/25 | 168 | 4930 | 29110 | 22576 | 457 | 13009 | 15927 | 19866 | 21677 | 24537 | 26548 | 27586 | 27900 | 28271 | |
| 07/26 - 08/01 | 168 | 5848 | 28514 | 21862 | 448 | 12739 | 16661 | 19125 | 21198 | 23352 | 25567 | 26964 | 27296 | 27567 | |
| 08/02 - 08/08 | 168 | 4377 | 27019 | 20203 | 490 | 10176 | 13829 | 17026 | 19830 | 22318 | 24369 | 25600 | 25899 | 26451 | |
| 08/09 - 08/15 | 168 | 5312 | 26063 | 19834 | 427 | 10689 | 14405 | 17172 | 19255 | 21513 | 23089 | 24445 | 25001 | 25385 | |
| 08/16 - 08/22 | 168 | 2943 | 24663 | 17491 | 441 | 8697 | 11326 | 14102 | 16407 | 18587 | 20206 | 22061 | 23158 | 23884 | |
| 08/23 - 08/29 | 168 | 2967 | 23168 | 16050 | 435 | 7284 | 10241 | 12593 | 14798 | 17069 | 19090 | 20594 | 21520 | 22409 | |
| 08/30 - 09/05 | 168 | 4704 | 21918 | 15867 | 403 | 7477 | 10099 | 13466 | 15081 | 17706 | 19313 | 19960 | 20634 | 21349 | |
| 09/06 - 09/12 | 168 | 2545 | 20631 | 14687 | 372 | 6517 | 9823 | 12958 | 14359 | 16403 | 17629 | 18316 | 19004 | 19666 | |
| 09/13 - 09/19 | 168 | 2641 | 19561 | 12180 | 392 | 4594 | 6494 | 8094 | 10600 | 12933 | 14855 | 16848 | 17310 | 17910 | |
| 09/20 - 09/26 | 168 | 2271 | 17521 | 11587 | 337 | 4890 | 6841 | 8555 | 10711 | 12441 | 14067 | 15383 | 15856 | 16448 | |
| 09/27 - 10/03 | 168 | 1235 | 15718 | 10775 | 293 | 4939 | 6847 | 8389 | 10225 | 11693 | 13032 | 13748 | 14265 | 14851 | |
| 10/04 - 10/10 | 168 | 1550 | 14472 | 8684 | 285 | 3828 | 4843 | 5936 | 7041 | 8677 | 9954 | 11590 | 12819 | 13502 | |
| 10/11 - 10/17 | 168 | 930 | 13076 | 7843 | 251 | 2958 | 4304 | 5701 | 6688 | 8463 | 9498 | 10201 | 11124 | 11782 | |
| 10/18 - 10/24 | 168 | 1112 | 12149 | 5839 | 224 | 2008 | 3188 | 4038 | 4494 | 5286 | 6421 | 7315 | 8599 | 10143 | |
| 10/25 - 10/31 | 168 | 1114 | 10111 | 5790 | 192 | 2295 | 3296 | 3873 | 4752 | 5862 | 6688 | 7510 | 8415 | 9263 | |
| 11/01 - 11/07 | 168 | 1089 | 10176 | 5203 | 179 | 2044 | 3057 | 3429 | 4011 | 5044 | 5967 | 6956 | 7610 | 8361 | |
| 11/08 - 11/14 | 168 | 913 | 8103 | 3767 | 143 | 1501 | 2112 | 2462 | 2842 | 3218 | 3829 | 4732 | 5610 | 6624 | |
| 11/15 - 11/21 | 168 | 485 | 7255 | 3514 | 137 | 1210 | 1852 | 2331 | 2837 | 3125 | 3739 | 4338 | 5189 | 6304 | |
| 11/22 - 11/28 | 168 | 540 | 6421 | 3195 | 125 | 1295 | 1588 | 2134 | 2498 | 2802 | 3425 | 3910 | 5157 | 5612 | |
| 11/29 - 12/05 | 168 | 535 | 5629 | 2519 | 100 | 1102 | 1376 | 1645 | 1902 | 2223 | 2503 | 3058 | 3582 | 4610 | |
| 12/06 - 12/12 | 175 | 290 | 5822 | 2609 | 106 | 958 | 1312 | 1480 | 1896 | 2266 | 2969 | 3344 | 4015 | 4764 | |
| 12/13 - 12/19 | 175 | 548 | 5136 | 2314 | 96 | 1000 | 1195 | 1400 | 1662 | 2024 | 2226 | 2607 | 3408 | 4617 | |
| 12/20 - 12/26 | 175 | 310 | 5308 | 2287 | 96 | 1064 | 1185 | 1385 | 1621 | 1879 | 2156 | 2600 | 3699 | 4379 | |
| 12/27 - 01/02 | 168 | 509 | 5813 | 2478 | 92 | 1171 | 1483 | 1738 | 2014 | 2177 | 2375 | 2798 | 3465 | 4303 | |
| 01/03 - 01/09 | 168 | 508 | 5498 | 2527 | 110 | 1071 | 1290 | 1545 | 1752 | 2093 | 2349 | 2895 | 4019 | 5009 | |
| 01/10 - 01/16 | 168 | 278 | 6107 | 2487 | 97 | 1230 | 1408 | 1631 | 1945 | 2185 | 2419 | 2876 | 3293 | 4614 | |
| 01/17 - 01/23 | 168 | 672 | 6506 | 3124 | 120 | 1454 | 1559 | 2087 | 2411 | 2784 | 3177 | 3675 | 4477 | 5539 | |
| 01/24 - 01/30 | 168 | 372 | 7586 | 3688 | 146 | 1601 | 1855 | 2283 | 2775 | 3189 | 3754 | 4504 | 5775 | 6597 | |
| 01/31 - 02/06 | 168 | 914 | 8600 | 4477 | 161 | 1939 | 2343 | 3181 | 3543 | 4054 | 4629 | 5456 | 6727 | 7734 | |
| 02/07 - 02/13 | 168 | 341 | 9766 | 5111 | 185 | 2246 | 3042 | 3954 | 4024 | 4535 | 5338 | 6186 | 7862 | 8793 | |
| 02/14 - 02/20 | 168 | 1299 | 11166 | 5604 | 215 | 2607 | 2992 | 3613 | 4093 | 4854 | 5319 | 6517 | 8839 | 10238 | |
| 02/21 - 02/27 | 168 | 1299 | 12370 | 6771 | 238 | 2908 | 3896 | 4790 | 5182 | 6105 | 6738 | 8738 | 10346 | 1372 | |

Table 26.



Solar Radiation

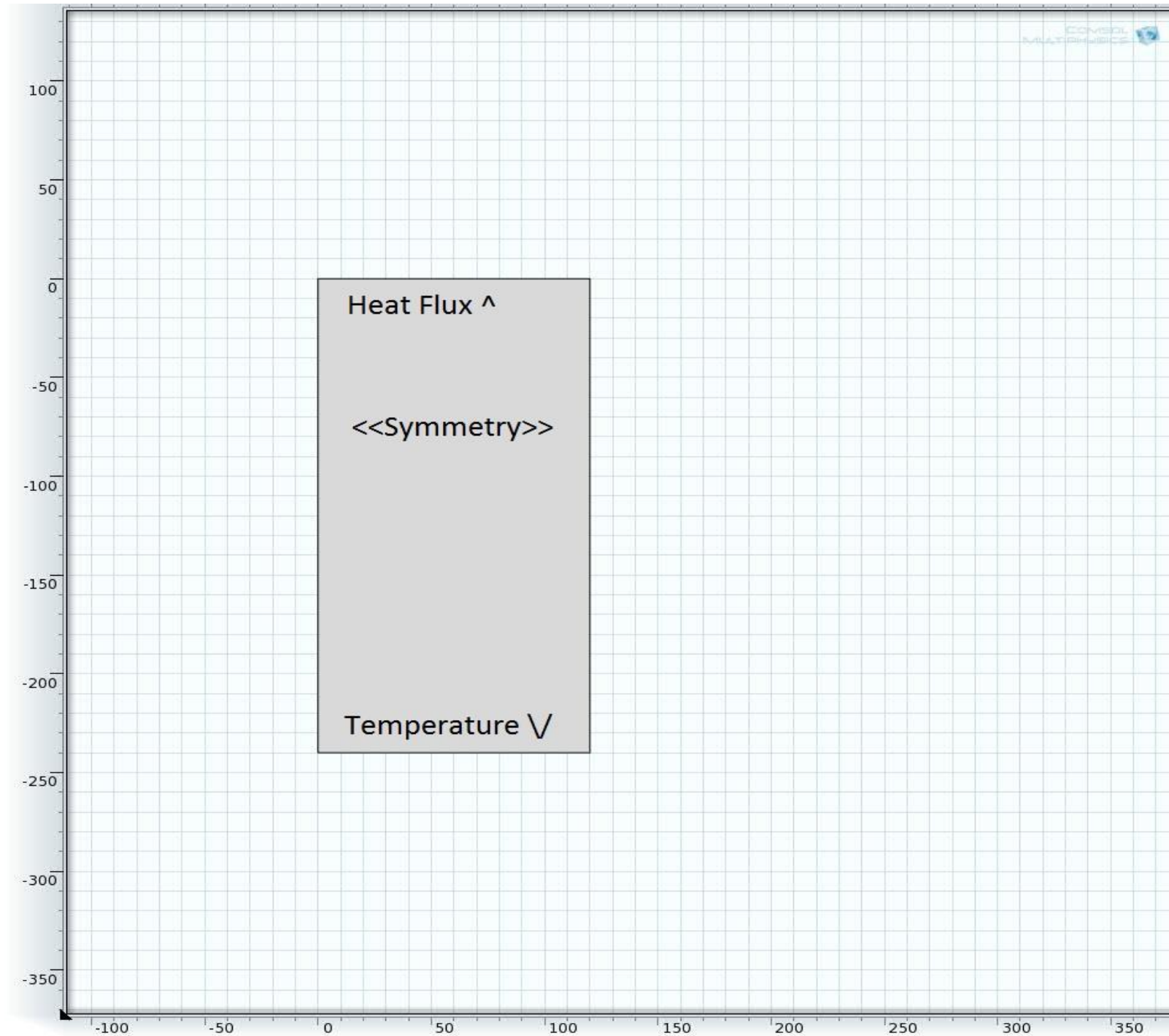


Parameters

| Parameter | Value | Units |
|----------------------|-------|-------------------|
| Heat Capacity | 600 | J/(Kg*K) |
| Density | 1660 | Kg/m ³ |
| Thermal Conductivity | 1.5 | W/(m*K) |
| Emissivity | .9 | |

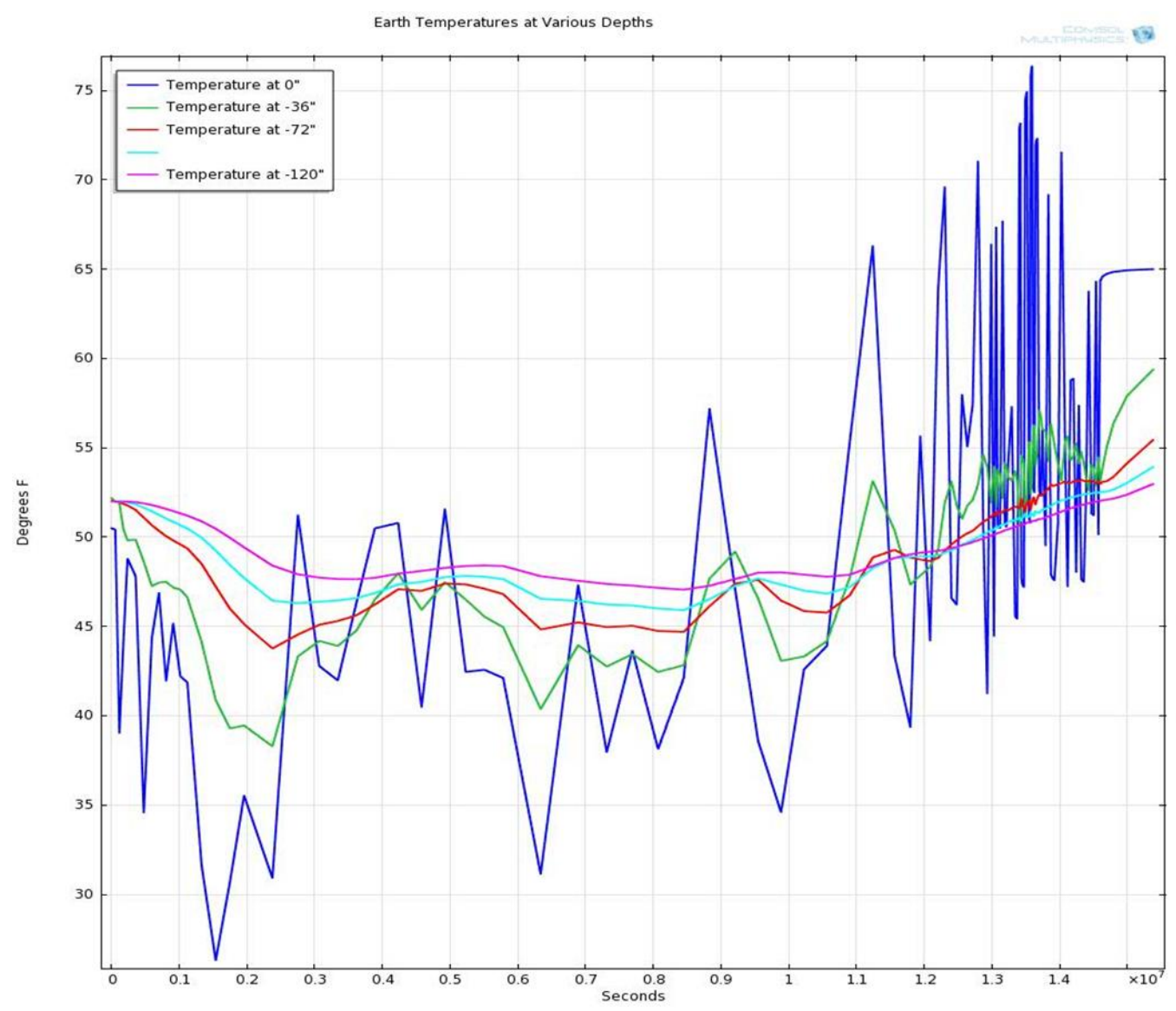


Geometry

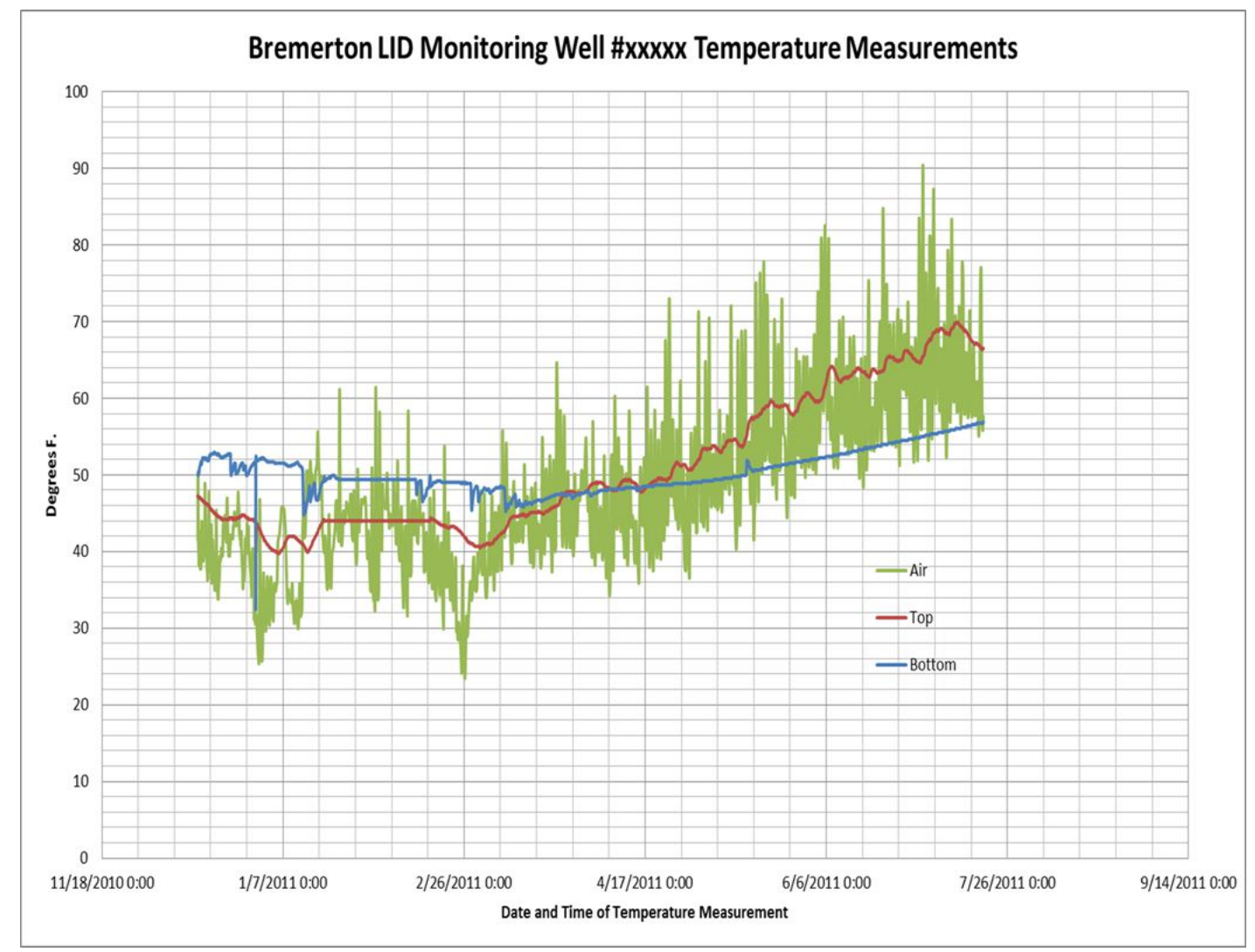


Validation Results

Simulated



Actual



References

Virginia Tech University (2009), “Earth Temperature and Site Geology”. <http://www.vt.edu/A1/A1.htm>.

Getz, Roger and Nicholas, Michael, “Probabilities and Extremes of Solar Radiation by Climatic Week”. NOAA Technical Memorandum NWS SR-98. 1979.

