KRC version 2 and 3: Thin/deep layers and long runs.

Hugh H. Kieffer   File=-/krc/Doc/thin.tex 2014may21 minor edit 2015dec22 2017feb25

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1 Introduction / Purpose

This started circa early 2014 with Robin Fergason's deceptively simple question about Mars surface temperatures: "What is the truth?".

KRC can not answer that, nor can any model. It is possible and essential to compare numerical model results with observations, recognizing that numerical models omit some physics, have numerical approximation errors, and may contain blunders. Observations can and always do involve calibration errors, measurement noise, and natural variations.

What can be done with a model alone is to assess the numerical approximation errors, and that is the purpose here. In particular, what is the effect of "spin-up", season-spacing, layer thickness and model depth for KRC.

In the middle of this, the double-precision version of KRC was developed and I have decided to use only that for this study to avoid any issue of build-up of numerical roundoff.

One must be careful if results near polar frosts are desired. I encourage individual studies for the particular circumstances of interest. Many of the studies here were done only at the equator where the diurnal effects are maximum.

1.0.1 Version 3 master

Differs from version 2 in that:
N2, step/days increased by factor of 4 to 1536, later to 384*4*256=393216
N1, number of layers, increased by 2 to 22, later to 50
Uses the feature to specify starting output Ls
Includes after the end-of-run 7 lines, which if inserted before the first "0/" line will set the model to run every sol and output the 3rd year. These are called "**soly**" (rhymes with Holy) runs.

2 Major runs

All runs used KRC version 3.1.1==311 except the two noted as 233==2.3.3 in the appendix. However, as of 2016jun22, neither of these is archived on H3
v241 should be the same as 233 except when using the Viking pressure curve.
v321 should be the same as 311

Mars sol is 1.0274910 days and its year is 668.61207sol ; Mars year for KRC is defined in the geometry block.

For run-length testing, must make the year an integral number of sols and need an integral number of reasonable-length seasons in a year. Choose to have $672{=}2^5 \cdot 3 \cdot 7$ seasons; this sets sol as 1.0223109 , 0.5% shorter than real. Can leave DELJUL as 1/42 of a MarsYear; 16.356974 days.

In order to concentrate on the effect of model parameters, some idealized objects used:
M0: Same as version 3 master.inp, except only the equator with elevation 0.
M1: As M0, but sol decreased by 0.5% to be 1/672 of a year
M2: As M1, but no atmosphere
M6: sol $\equiv$ 1 day and year $\equiv$ 720 days, no atmosphere, skip DelJul=16.
M7: as M6, and eccentricity =0
and several of the tests were done only at the equator.

All output in /work1/krc/test *.t52

2.1 Double precision versus single

Run with the version 2 master and 5 latitudes. Sol = 1/672 of a year. Exercise most of the KRC capabilities. Basin input file in *thin4.inp* Cases:

1. deep: N2=1538 time steps/sol, normal FLAY=.18 and RLAY=1.2, N1=26 layers (most layers must be first case). Total depth 102 diurnal skin depths (D) or about 3.9 annual skin depths. No atmosphere

2. thin: Flay=0.08664, a little less than 1/2 normal, total depth 49.1 D

3. 1536: normal FLAY, 22 layers, total depth 48.6D or 1.85 annual skin depths.
Holds for all the following cases.

4. 384: N2=384, traditional for KRC

5. dual: As above, IC2=7 Ice as the lower material
6. KofT: As above, with T-dependent properties
7. Kcon: T-dependent code, but constant properites
8. Atmos: Mars atmosphere with constant pressure, homogenous, T-constant properties
9. Viking: as above, with Viking pressure curve and variable Frost albedo and temperature

The primary metric is the mean value of the difference in Tsur through a sol, R*8 - R*4, $< \Delta T_s >$, here called **DATs** (ADTs is unpronounceable). The ratio of this average to the average of the absolute difference, $< \Delta T_s > / < |\Delta T_s| >$, is 0.96 so the preponderance of ΔT_s are of the same sign through a day.

2.2 Skip versus soly

KRC normally uses extrapolation to advance between seasons, see §3.2.7. in [1] however KRC can be run with no extrapolation; computing the insolation geometry every sol and effectively running continuously. Both the former ,"skip" and the latter, every-sol or "soly" methods were used for long runs and the results compared. The incentive for "skip" runs is execution speed and generating manageable files for mission model sets. For the two runs described here, both skip was 12 times faster than soly.

Done using M2 object. Skip run and saved for 6 years. Soly has 2 year spin-up then save for 4 years. Eight cases with I=200 run:
1: 1536deep; 1538 time steps/sol, normal FLAY and RLAY, 26 layers. Total depth 102 diurnal skin depths (D) or about 3.9 annual skin depths.
2: 1536thin; Flay=0.08664, a little less than 1/2 normal, total depth 49.1 D
3: 1536; normal FLAY, 22 layers, total depth 48.6 or 1.85 annual skin depths.
Holds for all the following cases.
4: 384; traditional KRC 16 steps/hour. This and the remainder have 22 layers
5: 768; 384*2 steps/hour
6: 3072; 384*8 steps/hour
7: 6144; 384*16 steps/hour
8: 1536atm; 384*4 steps/hour and default Mars atmosphere.

Skip-soly is nearly the same every year, Figure 1, with the exception of case 1, which has a secular trend. Differences are largely under 0.1K, shown in more detail in Figure 2. Jumps in the difference are associated with changes in the number of convergence days (NDJ4) before the asymptotic extrapolation; the size of these jumps, typically under 50 mK may be taken as an indication of the numerical error in the extrapolation.

There is little variation with the number of time steps, as seen in Figure 3 where the outliers are the atmosphere and deep cases.

Secular trends in convergence were visualized by forming the diurnal averages and subtracting the values for the final year from each of the earlier years. By the start of year 3, the difference is less than 2 mK for the skip models, Figure 4; the asymptotic extrapolation handles the deep model particularly well. For the every-sol models, Figure 5, the difference is less than 4 mK after a 2-year spin except for 30 mK for the deep case, which only slowly diminishes and would be larger if the run extended beyond 6 years.

The effect of a deeper run or using thinner layers is less than 0.1K, Figure 6. A double-deep model has only a 0.2K effect, similar to that for a difference in iteration days.

DATs are less than 0.1 K except near the pole, Figure 7; the source of these differences has not been identified.

The number of days to convergence is key to the Tsur differences. For instances (season, latitude, case) where NDJ4 was the same, $< |T_s| >$ is 23 mK, where different, 86 mK. NDJ4 is least changed for Latitude 0

tttmod @757; columns are each latitude; rows are cases.

```
Number of NDJ4 differences
Lat -30.     0.    30.    60.   87.5
      5      0      0      7      6  deep
     17      1      0     12      1  thin
     11      0      1      5     13  1536
     10      5      0      0      1  384
     17      0      3     17      8  dual
      6      0      0     23     33  KofT
     15      0      1     18      7  Kcon
      3      0      1      4      2  Atmos
```

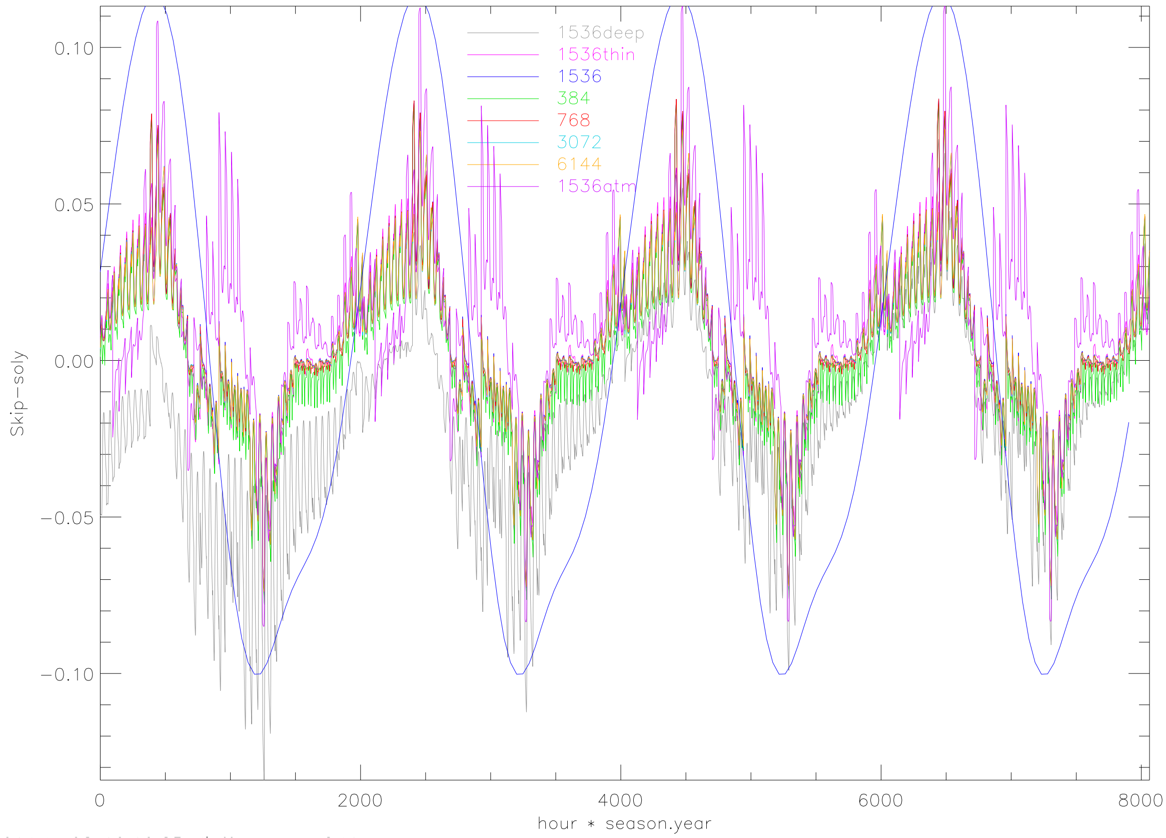

Figure 1: Skip-soly for every hour at the skip seasons for years 3 through 6. The smooth blue curve is variation of the diurnal average attenuated by a factor of -80 and phase offset of -20°. tm41.eps

4	0	2	2	0	Viking

Mean Abs Delta Diurnal Mean Tsur: mK

Lat -30.	0.	30.	60.	87.5	
7.6	4.0	5.2	24.6	118.9	deep
7.1	3.2	4.7	21.5	82.0	thin
7.4	3.4	4.6	22.3	77.9	1536
4.3	1.9	4.6	14.0	48.6	384
25.3	7.8	12.9	55.2	69.7	dual
18.9	19.2	27.5	36.1	121.5	KofT
24.8	8.0	11.0	53.7	80.3	Kcon
5.0	2.1	4.0	4.6	3.1	Atmos
4.9	2.3	3.5	5.5	2.6	Viking

2.2.1 Timing and data volume

For the "thin4" set of runs. Skip runs with 5 latitudes, soly (an "e" in the file name) runs with only -30°. -8 in name means R*8 version.

thin-	.t52 size	Total time, s.	Allowed cases
4	13.6M	5.996	RASE=23.43
48	30M	8.300	‘‘
4e	29M	5.433	RASE= 10.89
4e8	57M	12.017	‘‘

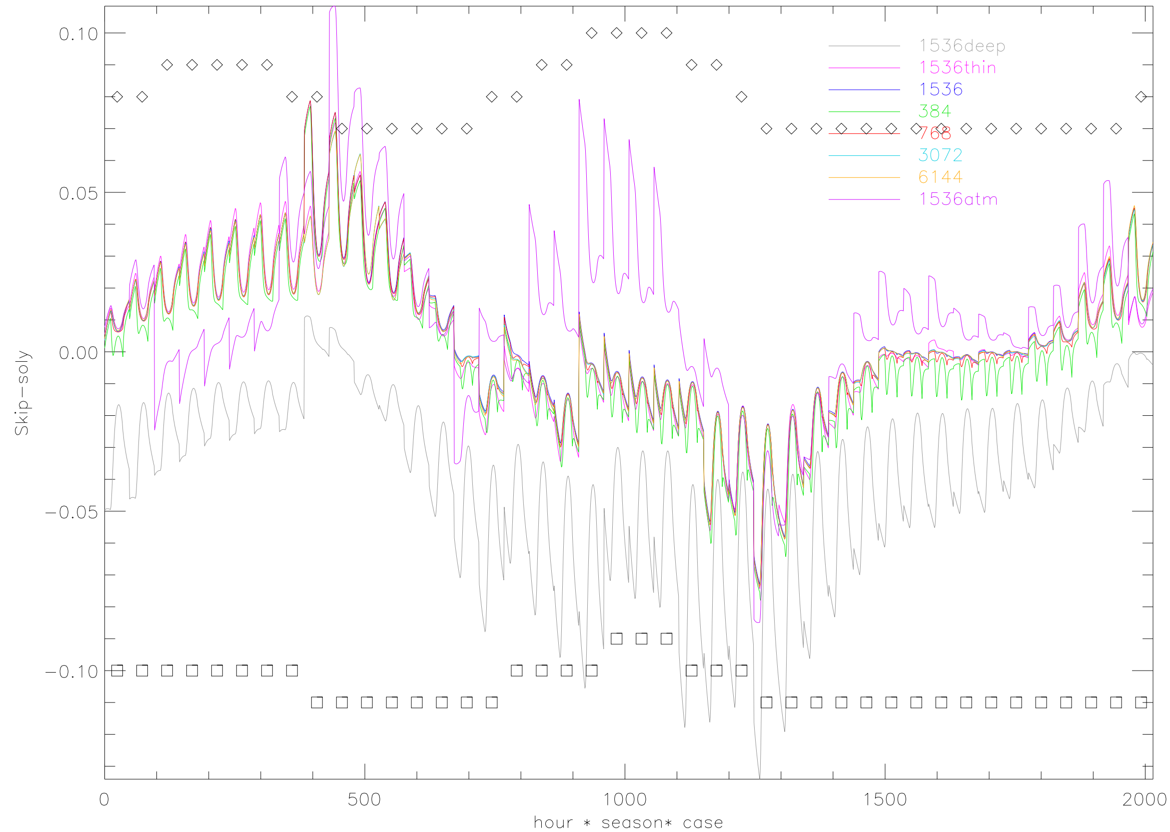

Figure 2: Skip-soly for every hour at all skip seasons in the last year. The diamonds indicate the number of convergences day (NDJ4, offset and scaled) for the 1536atm case; the boxes for the 1536deep case. tm42.eps

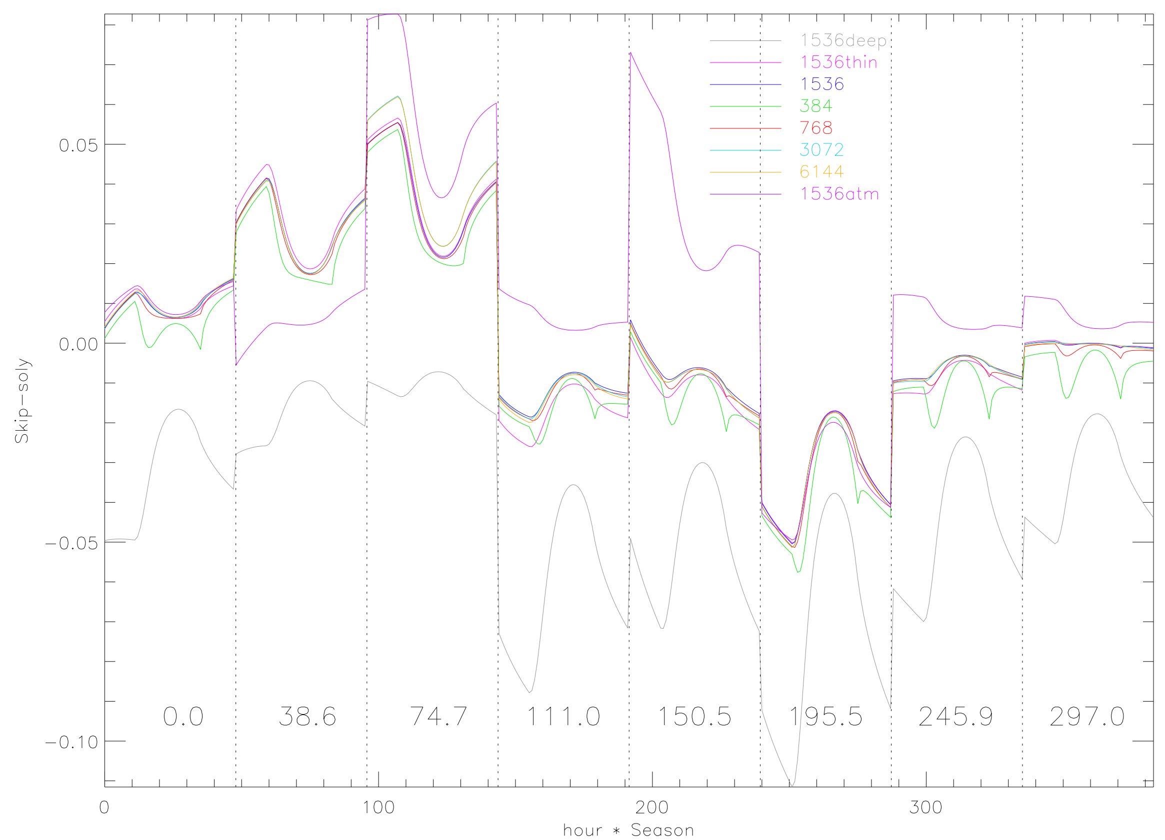

Figure 3: Skip-soly for every hour at 8 seasons spaced through the last year. tm43.eps

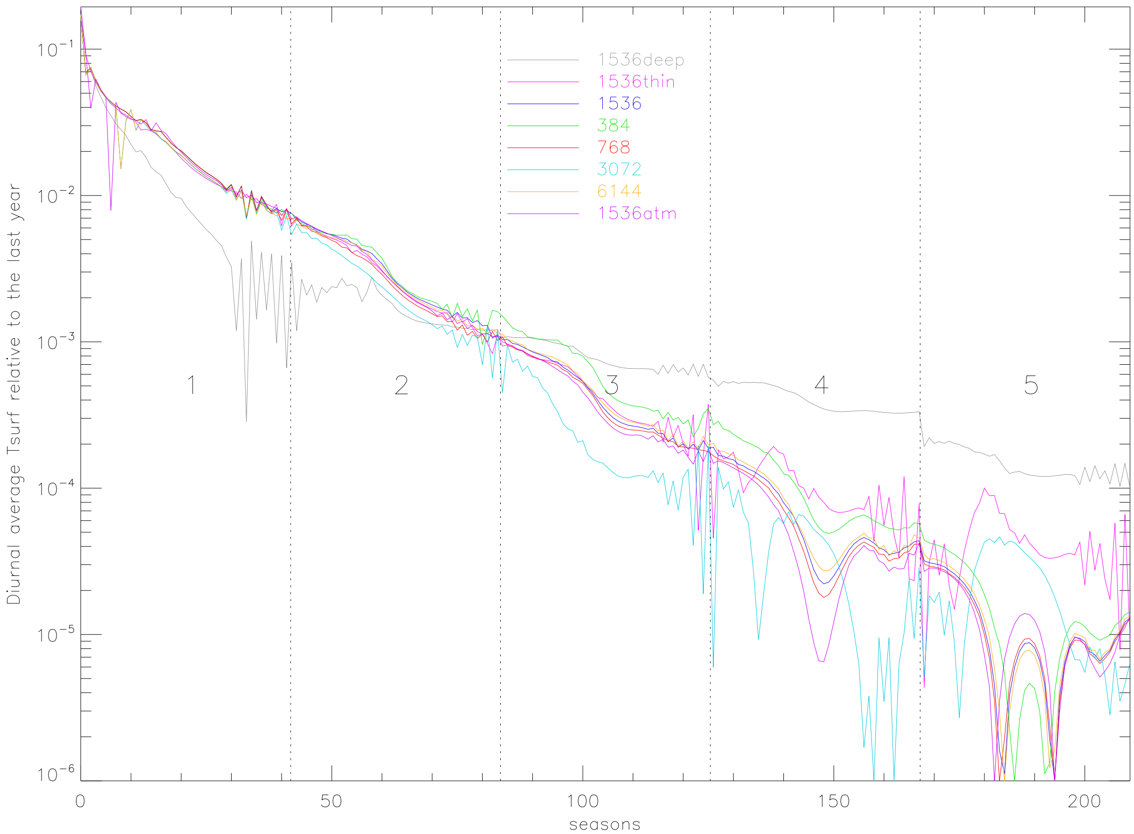

Figure 4: Residuals in diurnal-average surface temperature for each year made by subtracting the values at the corresponding season in the last year of the run. Shown are the absolute values; all values were negative. The model years are indicated with vertical dotted lines at the end of each year. tm52.eps

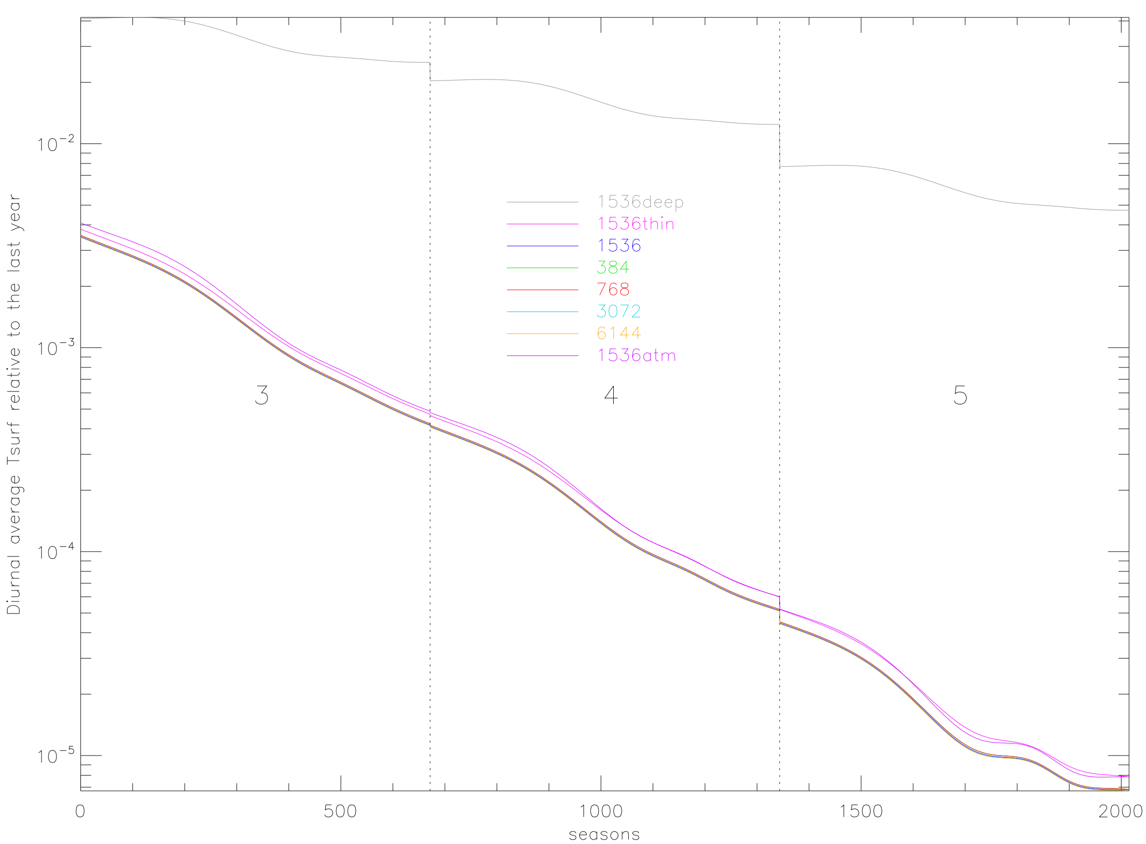

Figure 5: As in Fig. 4 but for the every-sol model; all values were positive. tm54.eps

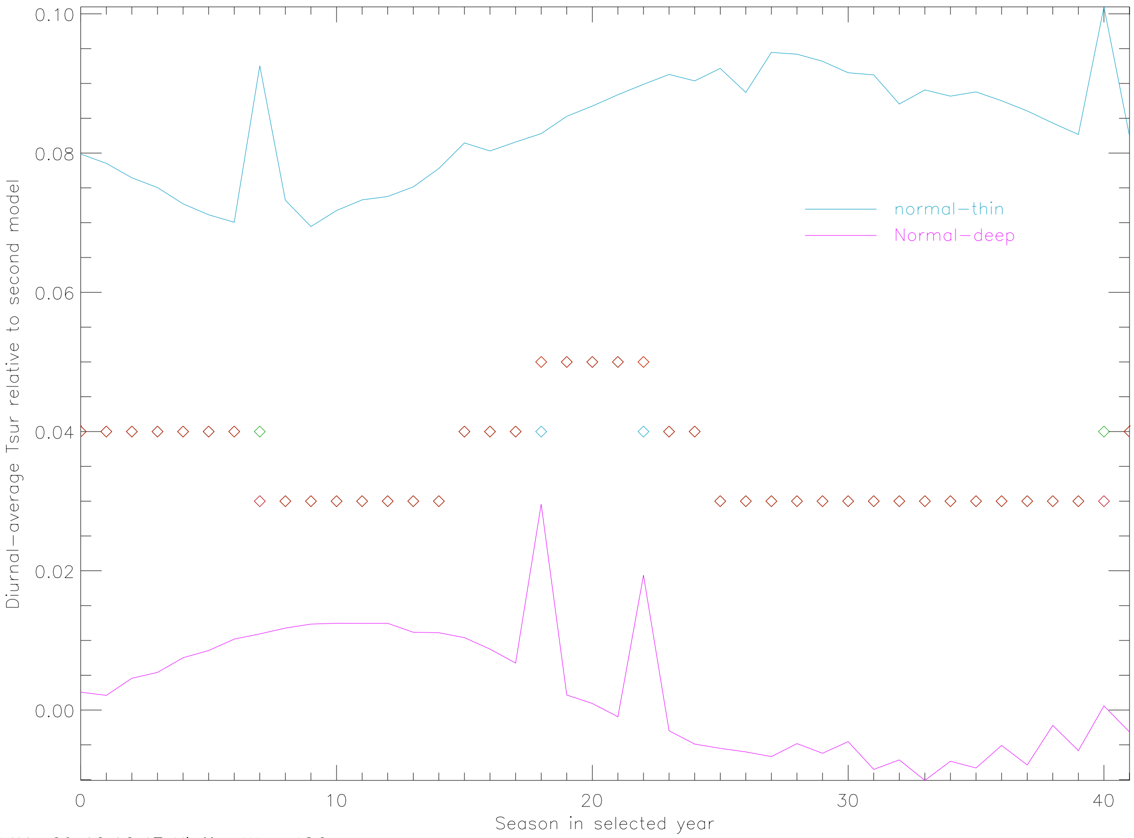

Figure 6: Skip models in year 3; the normal model (case 3) compared to a double-deep model (case 1) and to a model with thinner layers (case 2). The two spikes in each curve are due to changes in the number of iteration days, scaled by 1/100 and plotted as colored diamonds; multiple diamonds at one season indicate the convergenge days differed. tm622.eps

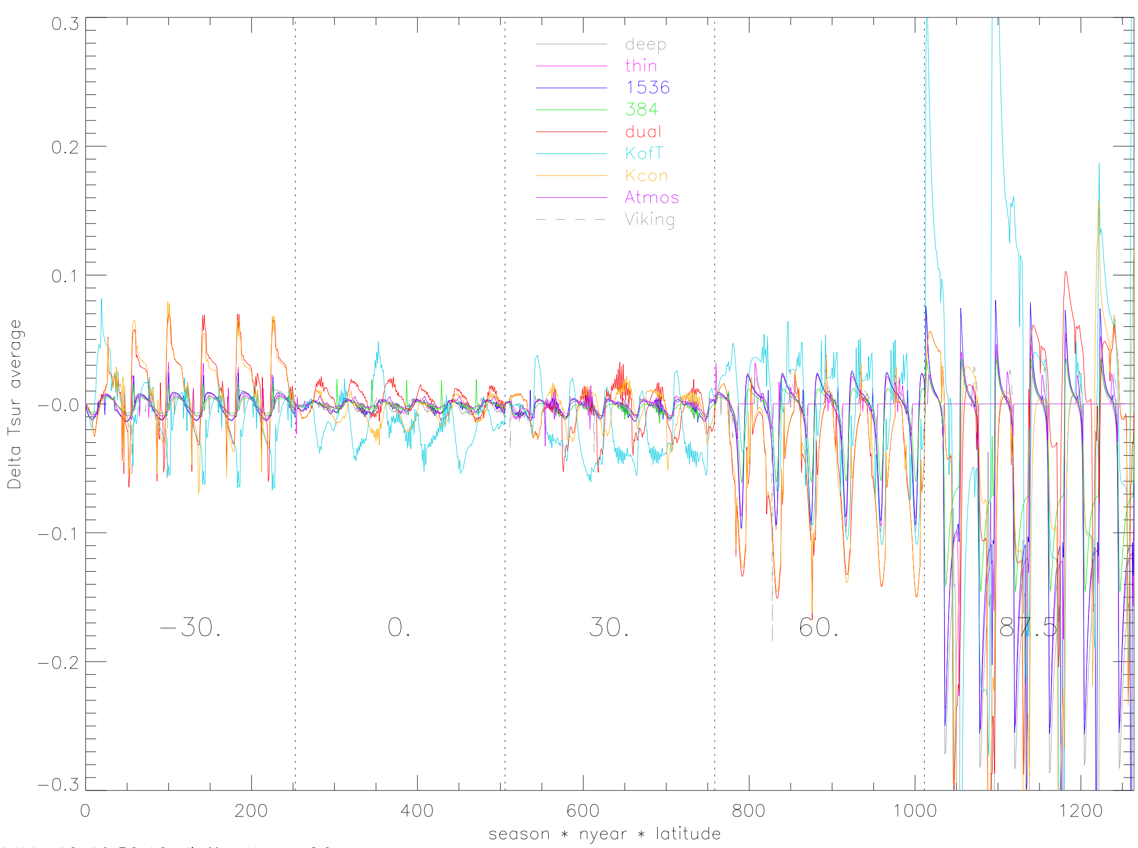

Figure 7: DATs for every season and year for all latitudes and cases. tm71.eps

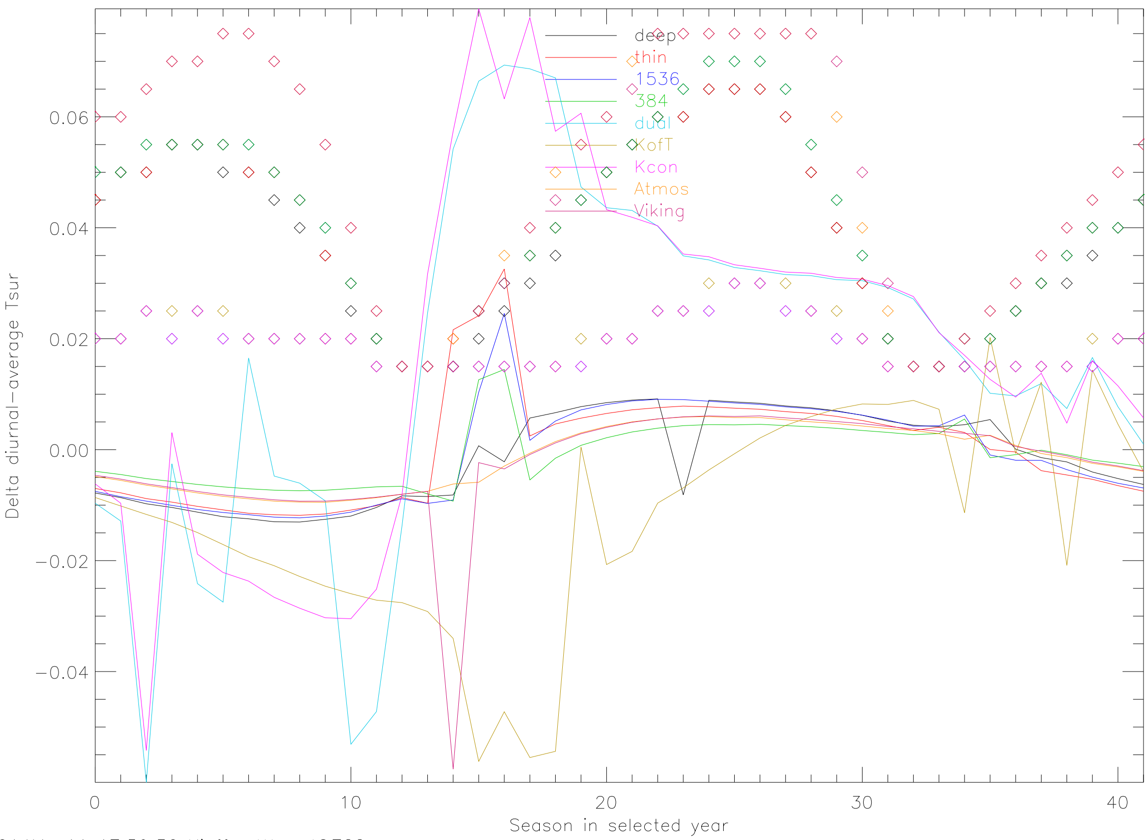

Figure 8: DATs for 30°S and year 3. Diamonds are the scaled change in number of convergence days. tm722.eps

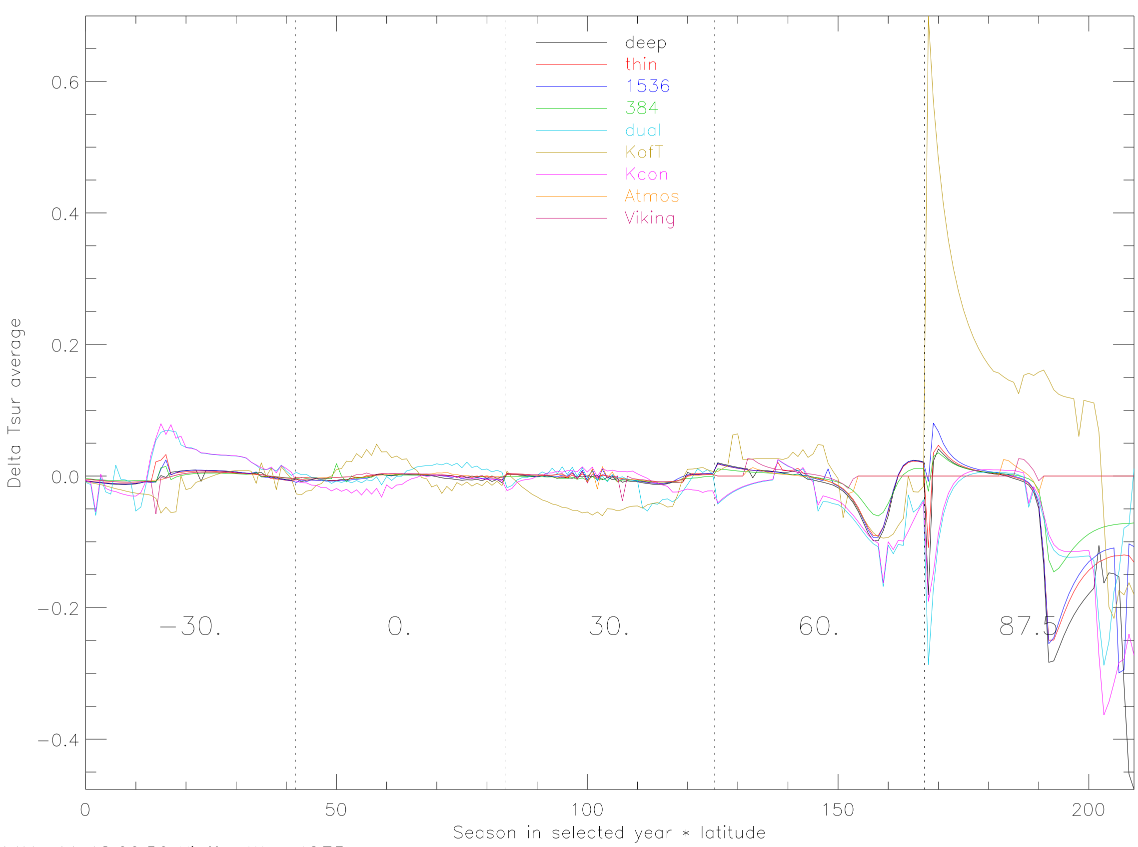

Figure 9: DATs for all seasons in year 3; sections show each latitude. tm73.eps

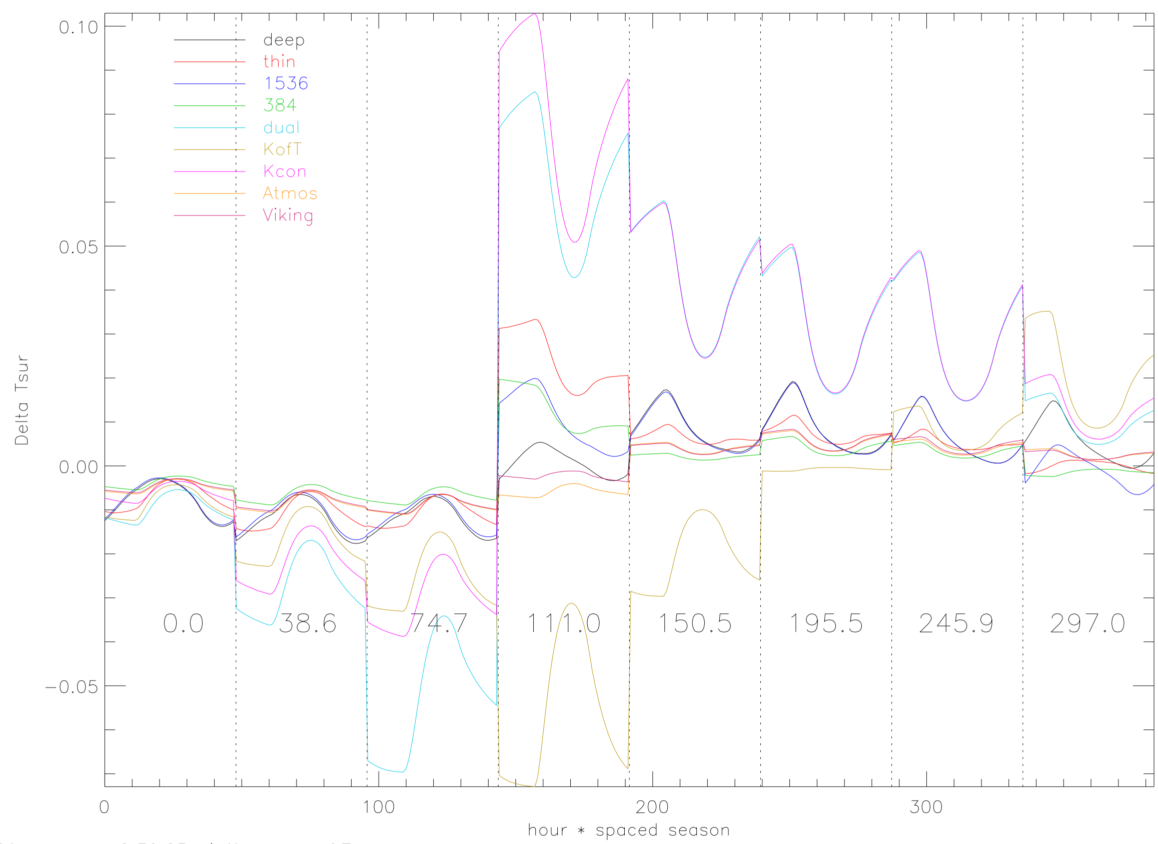

Figure 10: ΔT_s as a function of hour for seasons spaced by 5 for -30°. The jump betweeen the 3rd and 4th seasons is also shown in Figure 8 between indices 10 and 15. tm74.eps

3 May 5 Email, modified to include figure

Gentlemen and Ladies:

Following lasts weeks telecon, I have set the double-precision version of KRC to allow fairly thin layers. Version 3 will accommodate a factor 256 more time steps than version 2, for a maximum of 393216; hopefully thin enough for virtually any need. Also, the maximum number of time doublings has been increased from 6 to 14.

For Inertia of 50., the minimum top soil layer of 32 micrometers. I have run an initial study of layer thickness, the figure is attached and may take some time to sink in. The first case is a "throw-away" of extreme total depth required because the number of layers in a KRC run is limited by the first case [TDISK must set some array sizes].

I have also attached a draft version of white-paper to myself about version 3; of interest here is only Section 2, which has some useful layer thickness relations.

Summary of the cases: Z= is the thickness of the upper material in meters. The number of layers was adjusted to keep the total depth about the same.

```
1: Start with normal master, Inertia=200
  Set the sol  PERIOD = 1.0 day
  Set the year  = 720 days [inside the geometry matrix]
  Set the orbital eccentricity = 0.  [inside the geometry matrix]
  Set the season step   DELJUL=16.0
  Set the lower material to rock: DENS2=2500., SpHeat2=647. [COND2=2.77]
  Set to spin-up for two years, then output the 3rd year
  Start at Ls=0.01
    The above are each minor changes; just to get a clean situation.
  Set to no atmosphere: PTOTAL=0.5
  Set the times/day: N2=1536  this is 4 times normal
  Set the first layer of lower material: IC2=5   Three real layers.
  Set number of layer N1=44  Needed because N1 not allowed larger than first case
2: Set N1=22, roughly normal                         Z=0.0252
3: IC2=3  I.e., one real layer of upper material       Z=.0069

4:  Inertia=50 and reset IC2=7   Z=0.0129
5,6:  Same as 2,3 above  Z=0.0063 and 0.0017

7: Set first layer thin, FLAY=0.0533 thinnest allowed in theory
    and reset IC2=7     Z=0.0038
8,9: Same as 2,3 above  Z= 0.0019 and  0.000512

10:  FLAY=  0.2665E-01   Factor of 2 smaller
     N2= 6144  Factor of 4 larger               Z= 0.000256

11:  FLAY= 0.1333E-01 Factor of 2 smaller
     N2=  24576  Factor of 4 larger        Z= 0.000128

12:  FLAY= 0.6663E-02 Factor of 2 smaller
     N2= 98304  Factor of 4 larger         Z=0.000064

13:  FLAY=0.3331E-02  Factor of 2 smaller
     N2= 393216   Factor of 4 larger        Z=0.000032

14: Only the lower material, so Z==0.
```

Diurnal curves for case Ls=0 for this fictional Mars-like planet for all these are shown in Figure 11; note that case 14 is the asymptotic limit for thin layers.

All cases 5 or more had secular Tsurf changes less than 0.1 K over the last year.

A study could be done of other changes that mimic extremely thin layers.

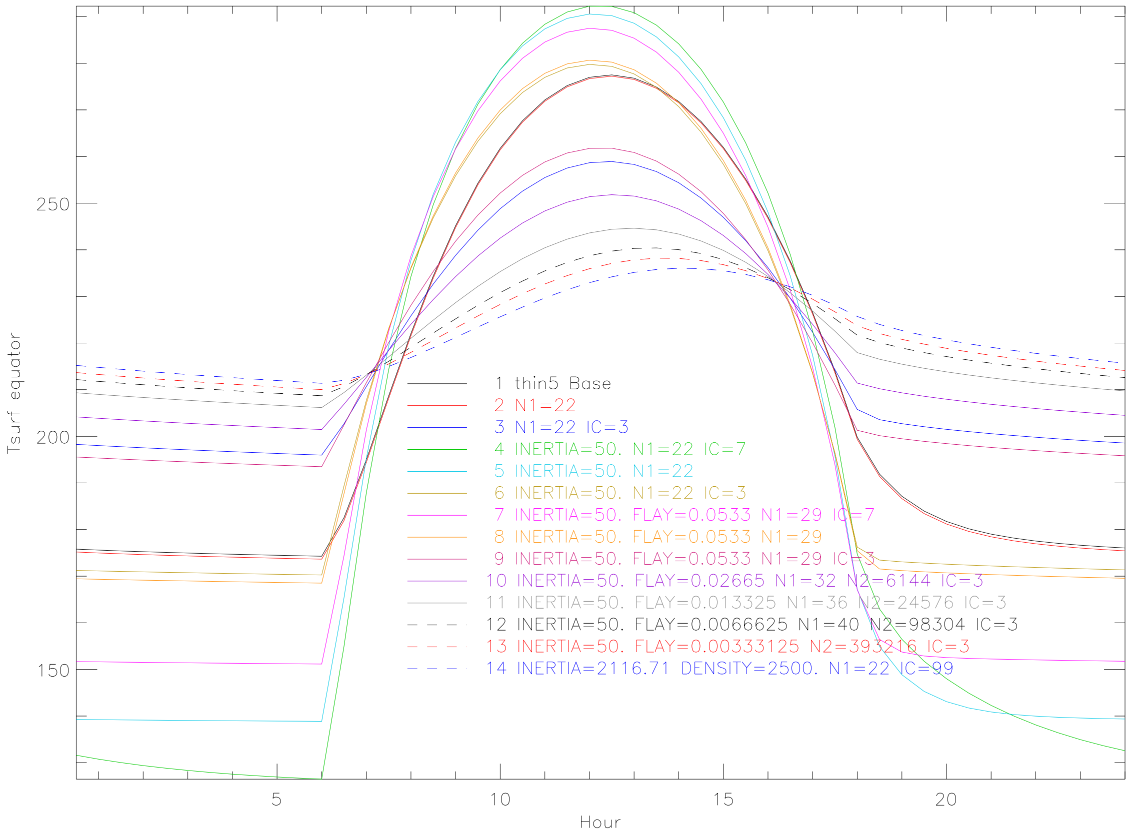

Figure 11: Diurnal surface temperature variation for models fluff (I=50) over rock (I=2117). See text for details. The first three cases have a surface material of I=200 for context. Greatest temperature variation is case 4, with fluff thickness of 1.3 cm. Case 13 has a fluff thickness of 32 μm. thin5.eps

FYI, below is a composite layer table of the last entry for each case. After case 1, an objective was to maintain the total dept in meters, the sixth column below, at nearly the same value. The KRC layer table will need some modification, as it has not enough significant figures in the upper layers for such use.

Case		___THICKNESS____		__CENTER_DEPTH__		Total	Converg.
	LAYER	scale	meter	scale	meter	kg/m^2	factor
1	44	3096.5500	99.2124	17019.1701	545.2881	******************	
2	22	56.0907	1.7971	296.6440	9.5044	25984.656	32.742
3	22	56.0907	1.7971	299.9363	9.6099	26264.807	32.742
4	22	224.3627	1.7971	1162.7904	9.3138	25519.438	32.742
5	22	224.3627	1.7971	1184.2174	9.4855	25954.427	32.742
6	22	224.3627	1.7971	1199.0972	9.6047	26256.502	32.742
7	29	238.0532	1.9068	1288.2084	10.3184	28176.136	36.859
8	29	238.0532	1.9068	1294.5531	10.3693	28304.941	36.859
9	29	280.5393	2.2471	1530.7769	12.2614	33461.873	51.190
10	32	242.3860	1.9415	1327.0281	10.6294	29000.074	38.213
11	36	251.3058	2.0129	1379.1344	11.0467	30132.914	41.077
12	40	260.5538	2.0870	1431.5223	11.4664	31274.624	176.625
13	44	270.1422	2.1638	1485.0203	11.8949	32441.939	759.455
14	22	8.2809	1.7971	44.4651	9.6498	26370.884	32.742

3.1 Timing

Case 13, N2=393216, 44 layers, one lat., took 25.1 sec on my computer (H3)

Note that this is a step time of 0.220 sec. At this resolution, it takes 390 time steps for the Sun to rise on Mars; a nicety that is not in KRC, which does it in 1 step, although the incidence angle to the center of the Sun is correct.

[Attach: thin5.jpg krcv3.pdf]

END May 5 EMAIL

Additional runs with related cases:

```
  1806848 May  5 06:21 thin5 N1=22:44  IC2=3:7  N2 to the max
      N2 adjusted to keep bottom similar meters
  1935872 May  6 10:17 thin6  skip; N1=22 IC=99  I=200 with N2 384 to 24576
                          and N2=1536 with I 50 to 400 and 1800+
 62899712 May  6 10:25 thin7  soly for 6 yr. N1=22 IC=99  N2 factor 2 I=200
          Total time [s]=   75.010590
thin7b ==thin7 except deljul=16  Total time [s]=   5.5571561
```

4 Early runs

```
thin1.t52 krc run R*4

thin2.t52 krcd run. R*8  with N2max=393216
END KRC   Total time [s]=   1.0418410

thin3  krcd, with N2max=393216 and MAXBOT=14E
END KRC   Total time [s]=   1.0278440

thin4  krcd    all cases 22 layers
flay=  0.0533000    0.0266500    0.0133250   0.00666250   0.00333125
N2=    1536         6144         24576       98304         393216
 Case 13  DTIME: total, user, system=   26.9289   26.9269    0.0020
      END KRC   Total time [s]=   36.377472
------------- the above runs deleted --------------

thin5
FLAY:   0.180000    0.0533000    0.0266500    0.0133250   0.00666250   0.00333125
N2  :      1536        1536        6144        24576        98304       393216
N1  :    22.0000      28.6751      32.4769      36.2787      40.0805      43.8823
 Case 13  DTIME: total, user, system=   25.0892   25.0872    0.0020
      END KRC   Total time [s]=    34.324783    no music

 Case  7  DTIME: total, user, system=   36.3625   36.3625    0.0000
      END KRC   Total time [s]=   73.485825
```

The logic in **kv3.pro** is getting complicated:
KRC cases are 1-based, combine and deltas are 0-based. Some actions:
    136, 123 , read two files, load tth and ttt
        48 clot ttt
        482 plot secular in ttt [uses tdd]
        483 CLOT tth
        484 print all tth and ttt cases
        485 edit and make combine ttc
        486 plot combine
        487 edit deltas
        488 do deltas tdd
        489 plot deltas

The change over years of the diurnal Temperature at Ls=0, is virtually independent of N2; relative to the last date (the first day of year 7) it reaches 4.4, 0.4, 0.05, 0.004 mK at the start of year 3, 4, 5, and 6 respectively.

Changing only the density of the upper material does not change the temperatures, only the scale and hence the layer thicknesses and depth.

4.1 Changing only N2 and Long runs

Run every sol (of 1.0 days) for spinup of 2 years (of 720 sols) for total of 6 years. Typical Mars homogeneous inertia of 200 with 22 layers; vary the number of time-steps per day from 384 to 384*64 in factors of 2. Results are in Figure 12

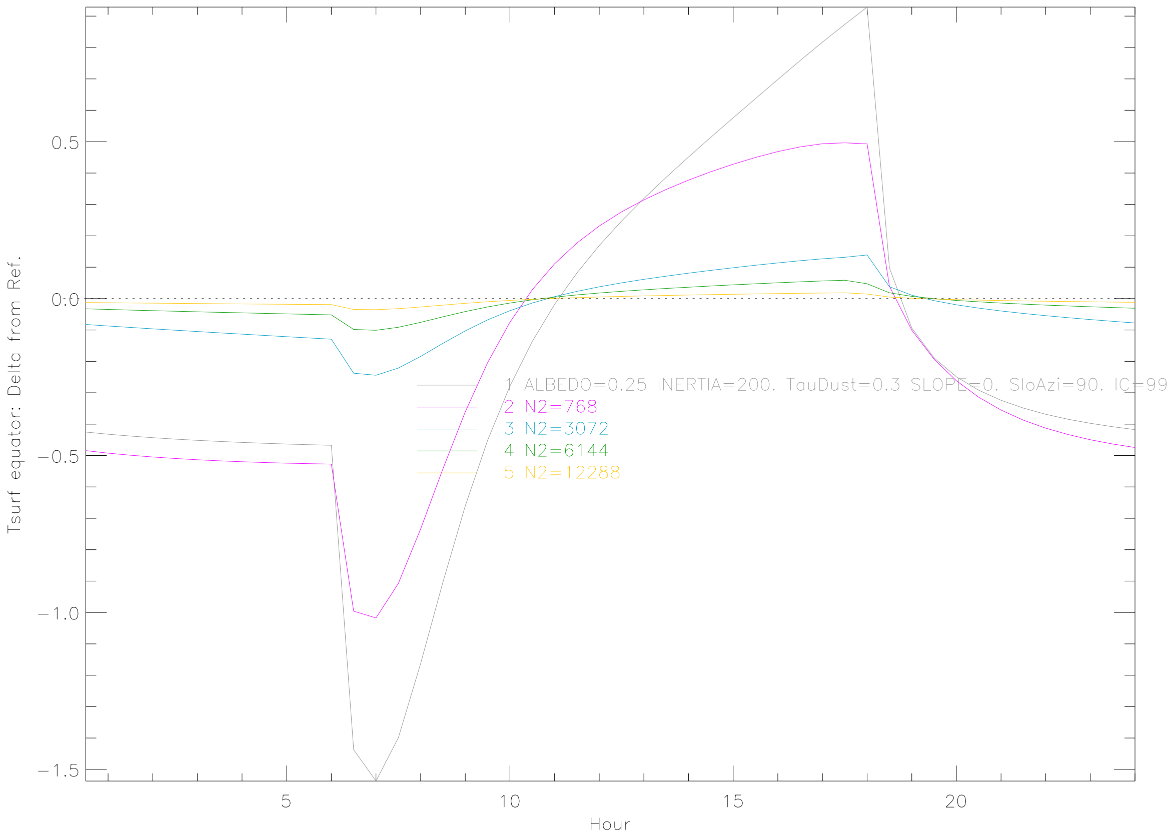

Figure 12: Effect of the number of time-steps per day; homogeneous I=200 with steps/day from 384 to 384*64 thin6c.eps

4.2 Non-uniqueness

Very thin layers will be hard to indentify as unique. Fig. 13 shows the difference in diurnal curves for some cases close to the minimum layer allowed.

1: with 32 μmlayer of I=50.
2: 10% I=50 and the rest bare rock
3: Entire surface I=1950
4: Entire surface I=2000

The entire range is -1:+1.5 K. Only at night do models 2 to 4 differ from the thinnest layer by more than 1K.

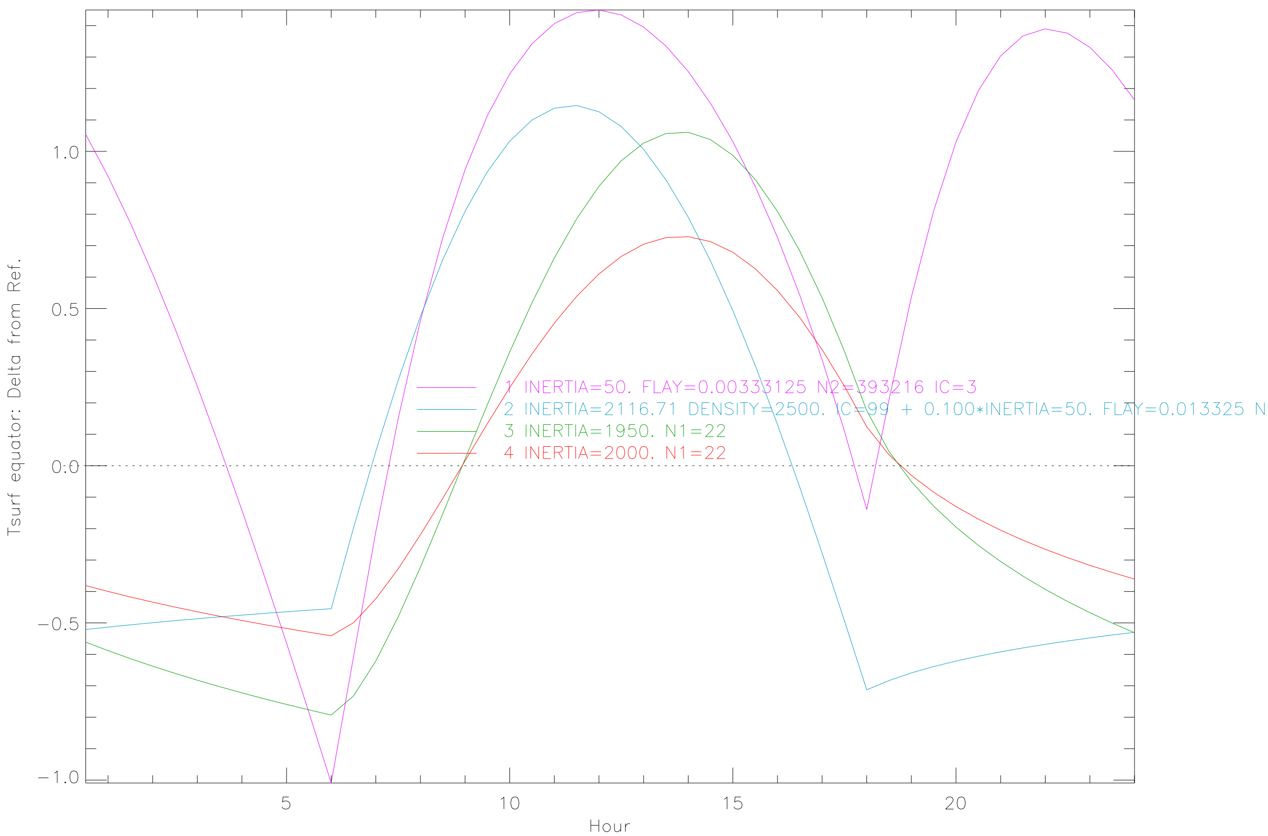

Figure 13: Temperatures relative to those for bare rock of I=2116.7; the minimum fluff layer thickness allowed in Version 3 and some similar cases. Skip model. thin6b.eps

A Files retained 2015dec22

All runs used version 3.1.1==311 except the two noted as 233==2.3.3 in time order:

```
 3555 May  6  2014 thin6.inp
 4025 May  6  2014 thin5.inp
 3801 May  8  2014 thin7.inp
 4093 May  8  2014 thin8.inp
 4329 May 21  2014 thin4.inp

 48912 May  4  2014 thin1.prt
 49232 May  4  2014 thin3.prt
 76130 May  5  2014 thin5.prt     1806848 May  5  2014 thin5.t52
 71460 May  6  2014 thin6.prt     1935872 May  6  2014 thin6.t52
 76132 May  6  2014 thin5b.prt    1806848 May  6  2014 thin5b.t52
 33758 May  6  2014 thin7b.prt    5193728 May  8  2014 thin7b.t52
 34068 May  8  2014 thin7.prt    62899712 May  8  2014 thin7.t52
 33758 May  8  2014 thin7a.prt
 10521 May  8  2014 thin7c.prt    1484288 May  8  2014 thin7c.t52
```

```
 38991 May  8  2014 thin8.prt
 39305 May  8  2014 thin8e.prt    5935616 May  8  2014 thin8.t52
 43678 May 10  2014 thin4e8.prt  58749440 May  8  2014 thin8e.t52
 42976 May 10  2014 thin4e.prt   29374976 May 21  2014 thin4e.t52  233
 47873 May 10  2014 thin4.prt    22531328 May 10  2014 thin4.t52q  233
 48597 May 10  2014 thin48.prt   30724352 May 10  2014 thin48.t52
                                 58749440 May 10  2014 thin4e8.t52

 2013 Jul 24 11:28:09=RUNTIME.  IPLAN AND TC= 104.0 0.10000 Mars:Mars
   104.0000      0.1000000      0.8644665      0.3226901E-01  -1.281586
  0.9340198E-01   1.523712      0.4090926       0.000000      0.9229373
   5.544402       0.000000       0.000000       720.0000       3397.977
   24.62296       0.000000      -1.240317      0.4397025       0.000000
   0.000000      0.3244965      0.8559126      0.4026359     -0.9458869
  0.2936298      0.1381285       0.000000     -0.4256703      0.9048783
```

4 and 8 have standard Mars geometry matrix. 42 seasons/year
5,6 and 7 have idealized orbit with 16 days per season

4: Described in §2.1

5: N2=1536 flay=.18 rlay=1.2 INertia=200
    1 single material
    IC2=5
    IC2=3
    Inertia=50 IC2=7
    IC2=5
    IC2=3
    flay=0.0533 N1=29 IC2=7
    IC2=5
    IC2=3
    flay=0.02665 N1=32 n2=6144
    flay=0.02665 N1=32 n2=6144

6: NLAY=22 N2=384
    cases 2:7, N2 increase by factor of 2 to 24576
    case 8, N2=1536 Inertia=50
    cases 9:11, inertia increase by factor of 2 to 400
    case 12:15, inertia=: 1800 1900 1950 2000

7: described in §2.2
N1=26 N2=1536 PTOTAL=0.5=no atmosphere
    2: FLAY=.0866434
    FLAY=.18 N1=22
    N2=384
    N2=768
    N2=3072
    N2=6144
    N2=1536 PTOTAL=546
7. 1.000=N3 99.00=GGT 9999=NRSET 1.000=DELJUL 4321=N5 1441=Jdisk 720=Notif
    7b. no initial changes 720=$2^4 * 3^2 * 5$ sols/year, 0 eccentricity
    7c N1=26
check by: fgrep -n Changed thin7*.prt
    7b differs from 7a only in DAU 1.55765 becomes 1.52371
    7 and 7c had DAU=1.465
7==7a==7b for cases. 7 is soly, 71 and 7b are??
    7c has N1=26, and 2nd case is FLAY=0.08664 and failed; no other cases

8: Similar to 7, but

```
2  3    1  'N3'         /| no daily iteration
1 39   99. 'GGT'        /| avoid iteration for convergence
2  9 9999  'NRSET'      /| avoid reset of layers
1 42 1.0223109   'DELJUL'     /| every sol
```

```
2  5  4033 'N5' / last of 6 years +1
2 12  1343 'Jdisk' / 2 year spinup
2 19   672 'Notif' / every year
```

References

[1] H. H. Kieffer. Thermal model for analysis of Mars infrared mapping. *Jour. Geophys. Res., Planets*, 118:451–470, 2013.