KRC Version 3.5.5 with eclipses, planetary fluxes and Photometric functions under an atmosphere

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Abstract

KRC has been expanded to handle two kinds of eclipses. Rather than wait for Version 4 with full longitude support, Version 3.5 has been generated with one-longitude-at-a-time support for three types of eclipses:
1) Lunar, or Daily: as for Jovian satellites.
2) Rare: in that the lead-up days did not have eclipse, as for Earth-lunar.
3) Solar: when the satellite casts a shadow on the planet.
The insolation profile through an eclipse has been modeled in considerable detail. However, PORB has not been changed, so the user will have to do some work to calculate the eclipse "bias" from perfect alignment. For Jovian (and similar) satellites, reflected and thermal radiation from the planet can be significant, especially during eclipse; a sinusoidal approximation for these in the form $F = c_1 + c_2 \cos(\nu - c_3)$ has been included for each. Atmospheres on the eclipsed body are treated for lunar eclipses but are ignored over the duration of a rare or solar eclipse. Other changes:
- Added the capability to write binary files of surface temperatures at every computed time-step on the last day of the last season for any set of cases.
- Separated the photometric function parameter from atmospheric parameters so that non-Lambertian surfaces may be used when there is an atmosphere. However, the atmosphere calculations still assume a Lambertian lower boundary, as this is a predicate for the 2-stream delta-Eddington calculations.
Version 3.5.5 is largely backward compatible with earlier versions 3.x, so that non-eclipse use is unchanged with the exception that the photometic function parameter which had been overloaded with the Henyey-Greenstein value is now change-line 1 38, (was DDT).

Documentation of 3.5.x before 2017dec08 has several important errors. Bugs related to eclipses were found in 3.5.4; and any results from that version should be redone.

1 Introduction

Terminology:
Occulting body: OB The body casting the shadow.
Eclipsed body: EB The body in shadow.
Eclipse body Surface Point: ESP The location on the EB for which calculations are done.
Bias The Sun:EB center line closest approach to the OB center, as a fraction of the OB radius; + is North.
Central hour The KRC hour at ESP at the center of eclipse.

Eclipse insolation profile includes the full geometry for round body occulting a round Sun. Simplifying assumptions for eclipse insolation profile.

1. Assume circular, uniform irradiance source (Sun)
2. Effect of planet atmosphere treats Sun as a point source. ? [atmosphere not implimented]
   Convolve this with the geometric extinction.

NOTE: The OB atmosphere effects became too messy, and are currently omitted!

KRC 3.5 assumes synchronous rotating satellites, so longitudes are not all the same as in earlier versions of KRC. For simplicity, specify surface longitudes as Hours from the sub-solar point at inferior conjunction (from the Sun) and increasing eastward (right-hand about the North pole).

The finite size of the EB is included in computing distances; in the Solar System, this is important only for Phobos shadow on Mars.

The symbols $<\!\!>\!\!>$ and $<\!\!<\!\!>$ are used here to bound direct quotes from articles or prior documents.

2 3.5.5

2.1 Things not backward compatible

The convergence parameter DDT has been firm-coded in KRC and real parameter 38 is now the reflectance photometric function key.

3 Users Guide

This guide is a supplement to prior KRC User Guides; it repeats virtually nothing. The basic model is that described in Kieffer12=[2]

Version 3.5 is mostly backward compatible with earlier versions 3.x, so that non-eclipse use is unchanged.

3.1 Input file

Suggest starting with an input file from the distribution, e.g.,*eurD.inp*, and modifying as you wish.

1. Generate the geometry matrix for the planet:satellite of interest, and cut-and-paste it into the input file. A matrix for Europa is in *PORBCM.mat* and in the suggested input file.
2. To invoke an eclipse, insert a change line 14 ; see §5.5. This eclipse will be in following cases until a change line '14 0 /' is used. If a Rare eclipse is specified, a binary file named *tfinexx.bin5* will appear in the running directory, where *xx* is the case number.
3. To invoke planetary fluxes, insert a change line 15; see §7.1. This will apply to following cases until a change line '15 0 /' is used.
   It may be helpful to look at the discussion in §B calculating the flux values.
4. To output a binary file containing the detailed surface temperature versus hour for one latitude, insert a change line 16; see §3.2. This will apply to following cases until a change line '16 0 /' is used.

If both eclipse and planetary heating are invoked in a case; the longitudes (expressed in Hours) should be the same. KRC does not check for this consistency.

3.2 Output files

Controlled by change lines:

KRC has traditionally output temperatures and other values every Hour (1/24th of the bodies day) or sub-multiple thereof, down to 1/4 Hour, the firm-code limit for N24 being 96. To track surface temperatures through an eclipse requires higher resolution. While the Daily eclipse calculations are done with a small modification of TDAY with no special output, a Rare eclipse will output a file of temperatures at high resolution (every fine-time step) for times around the eclipse.

.t52 The normal KRC type 52 file specified by a change line '8 5 0 name'. To maintain compatiblity with earlier versions of KRC, this file is not changed. It will contain the eclipse results for "lunar" eclipses, but ignores "rare" or "solar" eclipses.

tfine "rare" or "solar" eclipses invoke fine-resolution in time and depth using the routine TFINE which outputs an additional binary file <run>*tfinexx.bin5* where xx is the 1-based case number. This file contains ASOL, FINSOL and upper layer temperatures at every fine time-step within eclipse for each latitude where an eclipse occurs. Header contains two ASCII vectors

caret-separated: N2, fine-time factor KFT, spare, followed by triples of: [J7,J9, latitude index] for each latitude that has an eclipse (and was stored).

!-separated: PARC, the values from input change-line 14 including the two defined by KRC.

'-separated: Depth of the fine layers stored; the first depth value will be negative, corresponding to the virtual layer,

but the first temperature value is the surface temperature.

Main array is REAL*8 [2 + [upper] fine layers, fine-time, latitude]. The first dimension will be up to MAXFK[=20], firm-coded in TFINE. The 2nd dimension is set by the longest eclipse possible, computed by ECLIPSE for a bias $b' = 0$, then doubled to cover the recovery phase after an eclipse. The number defined for a latitude is (J9-J7+1)*KFT. The 3rd dimension is latitudes stored, which may be limited if the array size would exceed MAXCCC[=5000000] 8-byte words, firm-coded in TFINE.

The hour associated with fine time-step I (1-based) in this file is: (J7+ I/KFT) * 24/N2

tout To address this in a generic way, the existing array `TOUT` that is already in a COMMON can now be written to a binary file on the last day of the last season for one latitude. This is invoked by a change line 16, containing the 1-based index of the latitude desired and the central part of the file name. Output file name will be <run><central>< *cxx.bin5* where *xx* is the case number, generated automatically by KRC. The 'run' will be the leading part of the output print file name. The recommended central part is

object
+ 'lat'
+ latitude in degrees with a following N or S as appropriate

Example:

```
16 1 'eurDlat0N'  / output file for Tsurf every time-step on last day of last season
```

This will generate an output file in the running directory for each case untill stopped by a change-line: "16 0 / "

3.3 fort.nn Debug output files

Controlled by debug codes in the optional 2nd line of an input file.

WARNING; these file names are intrinsic to the FORTRAN language and will be the same for each run. You must rename any you wish to retain.

Data in each file is cumulative within a KRC run.

3.3.1 fort.42

Done IF (IRET.LT.1 .OR. IDB5.GE.2). Written in TFINE in layer loop 3.
WRITE(42,'(A,I4,2G12.5,F8.1)') 'J,BLAF,SCONVF,QA',J,BLAF(J),SCONVF(J),QA
J: layer
BLAF: layer thickness
SCONVF: safety factor before consideration of doubling
QA: doubling factor
J drops to 2 for each new case.

3.3.2 fort.43

Done IF (IDB5.GE.4). Written in TFINE at start of each day loop.
Cases are appended. Format is:
22 FORMAT(99F8.3)
23 FORMAT(99G12.4)
,*) 'N1...YTF',N1,FLAY,RLAY, KFL,N1F,RLAF
,23)(XCEN(I),I=1,N1) center depth
,22)(TTJ(I),I=1,N1) starting temperature of each coarse layer
,23)(YTF(I),I=1,N1) temperatures of the upper N1 fine layers
,23)(BLAY(I),I=1,N1) thickness of coarse layers
,23)(BLAF(I),I=1,N1) thickness of the upper N1 fine layers
,23)(XCEF(I),I=1,N1) center depth of the upper N1 fine layers
,*)'C_END'
,23)(XCEF(I),I=1,N1F) center depth of all fine layers
,22)(TTF(I),I=1,N1F) starting temperature of all fine layers
,23)(FA1(I),I=1,N1F) FA1 for all fine layers
,23)(FA3(I),I=1,N1F) FA3 for all fine layers
' N1...YTF' at start of each new case

3.3.3 fort.44

Done IF (IDB5.GE.6 .AND. (JJ.LT.(J7+3) .OR. ABS(JJ-J8).LT.3))
Written in TFINE at end of each fine-time loop, for each day.
WRITE(44,244) JFI,FINSJ,TSUR,ABRAD,SHEATF,POWER,FAC7,KN
244 FORMAT(I6,f7.4,F8.3,3F11.5,G12.5,I4)

JFI fine time index
FINSJ fraction of sun visible
TSUR Surface temperature
ABRAD surface absorbed radiation
SHEATF upward heat flow to surface
POWER unbalanced flux at surface
FAC7 = KTF(2)/XCEF(2) thermal conductivity/thickness of fine layers
KN bottom layer for this time interval

JFI jumps up to skip central eclipse. JFI drops to 1 for each new case.

3.3.4 fort.46

Done IF (J7.GT.0 .AND. IDB5.GE.7)
Only on last day of last season for Rare eclipse.
Written in TDAY at the end of the time loop
FORMAT(I6, F9.4,F8.3,2F10.4 ,F10.5,G12.5,I4)

JJ coarse time index
ATMRAD hemispheric downwelling IR flux
TSUR Surface temperature
ABRAD surface absorbed radiation
SHEATF upward heat flow to surface
POWER unbalanced flux at surface
FAC7 = KTT(2)/XCEN(2) thermal conductivity/thickness. Will be redone if not LALCON
KN bottom layer for this time interval

JJ drops to 1 for each new case.

3.3.5 fort.47

Done (IDB5.GE.4) . Written in TDAY each day at the start of eclipse
22 FORMAT(99F8.3)
(TTJ(I),I=1,N1) coarse T
Written in TFINE after end of time loop
(TTF(I),I=1,N1F) fine T
(TRET(I),I=1,JLOW) T spline interpolated onto coarse layers
JLOW is returned by TFINE(2,..) as the last argument, then printed to IOSP as the 2nd item on line starting 'End eclipse: JJ,KG...'
Cases are concatonated

3.4 New routines

There are two major new routines:

ECLIPSE eclipse.f Calculates the detailed insolation history of a circular body occulting a uniform round source.

TFINE tfine8.f Increases the depth (layer) and time resolution beyond that of TDAY to follow the details of a Rare eclipse.

EVMONO3D evmonod.f Evaluation of 3rd-degree polynomial with scaling. This is a modification of EVMON03 that has the scaling coefficients firm-coded, thus two less arguments, and is 9% faster.

ORLINT8 orlint8.f Linear interpolation over ordered (increasing) input X for ordered output X. Optional interpolation method between coarse and fine layer T profiles.

Also utility routines **STRUMI** and **STRUMR8**, and two routines uses only in testing that can modify parameters: **GETPI4** and **GETPR8**.

4 Liens

1) Type 52 output for Rare eclipses in version 3.5.5 contains un-eclipsed values until a discontinutity at the end of the eclipse, with the proper details in a separate binary file; these are merged in a post-run IDL routine. The TFINE algorithm could be moved into an optional (LRARE only) loop entirely within TDAY so that the Type 52 file had the eclipse results.

2) The layer TMIN and TMAX do not consider temperatures during a Rare eclipse; they do consider the remainder of the eclipse day. However, only the near-surface TMAX would likely be affected by rare eclipse.

3) Use of a special change line to toggle TOUT binary file is crude. Should be moved to an integer when the size of KRCCOM ID is increased.

4) Eclipse obscuration calculations are done in time steps scaled to the orbit period whereas they are applied in time steps scaled to the sol of the EB. Thus lunar eclipses apply only to synchronous rotating satellites.

5) How to describe eclipse that grazes an EB pole, where all hours are eclipsed, but only briefly! ?

4.1 Approximations

Bodies are spherical. However, one could use appropriate radius for the OB at the bias of interest.

Planetary radiation considered to come from point source at center of OB. See §7.3 Crescent shape of reflected sunlight not considered.

Center-of-body timing: attenuation of insolation does not consider the offset on EB surface point from the OB:EB centerline. Tiny effect. A good approximation is to offset local hour by $\frac{r}{2\pi M)} \cos([\frac{H}{12} - 1]\pi) \cos\theta/24$ where θ is latitude on EB; this is less than 3.E-5 Hour for Europa.

5 Eclipse design

Length input parameters are in physical units of km, but within the ECLIPSE routine, all distances are arbitrarily scaled to a characteristic length taken as the semi-major axis (radius, in this simplified case) of the mutual orbit of the occulting and eclipsed bodies.

5.1 Notation

"time-step" means as used in TDAY unless specifically called a fine time-step (or f-time) as used in TFINE.

Define a few angles and variables:
b: Bias: closest approach of the sun-line to the center of OB, as a fraction of OB radius.
    b' is the value at a specific latitude on EB.
H_c: KRC hour at the center-of-eclipse for the satellite surface point of interest.
H_U: the heliocentric range in Astronomical Units
J_7=J7: Last 1-based time step before the start of eclipse phenomona
J_8=J8: First 1-based time step after the end of eclipse phenomona
K_L: fine layer factor for rare eclipse
$K_T \equiv K_L^2$; fine-time factor for rare eclipse
M: mutual orbital radius between the centers-of-mass of the OB and EB.
    This is the normalization scale for all distances
N_2=N2: KRC number of time-steps per sol
p: co-latitude of the sub-OB point on EB
P_O: co-orbital period (days)
Q: Distance from center of OB to ESP
R, r: Angular radius of the larger/smaller of the Sun and OB seen from the EB
R_O, r_O: radius (km) and normalized radius of the OB
R_E, r_E: radius (km) and normalized radius of the EB
r_S: Normalized radius of the Sun in the working plane; $\approx \alpha M$
U: the Astronomical Unit in km.
x: In-plane separation of OB and EB at first contact. ??
z: Zenith angle of the center of OB at ESP (level surface)
α: Angular radius of the Sun from OB:EB system, radians

β: orbital angle from center to outer edge of eclipse penumbra
ν: orbital longitude; zero when EB is at inferior conjunction as seen from the Sun
ϕ: Angle of ESP from noon, radians
ψ: orbital angle from the center of the eclipse $\psi = \nu - \pi$
θ: Latitude on the EB

5.2 Basic eclipse phenomenon equation

Basic assumption is that a round source (the Sun) is being blocked by a round Occulting Body (OB). The formula from the intersection of two circles is taken from http://mathworld.wolfram.com/Circle-CircleIntersection.html

$$A = r^2 \underbrace{\arccos\left(\frac{d^2 + r^2 - R^2}{2dr}\right)}_{ANG2} + R^2 \underbrace{\arccos\left(\frac{d^2 + R^2 - r^2}{2dR}\right)}_{ANG1}$$
$$-\frac{1}{2}\underbrace{\sqrt{(-d+r-R)(-d-r+R)(-d+r+R)(d+r+R)}}_{SQP} \qquad \text{eq : e14} \tag{1}$$

where r and R are the radii of the two circles and d is the separation of their centers.

Implement using B for the radius of the Bigger circle (which might be either r_O or r_S) and R for the other, with many intermediate variables and tests for speed and avoiding faults.

If $d \geq (B + R)$ then $A = 0$; if $d \leq (B - R)$ then $A = \pi R^2$.

The fraction of sun-light reaching the surface of EB is $F = 1 - A/(\pi r_S^2)$.

If B is the Sun, then have an annular eclipse and $F_{min} = 1. - (R/B)^2$. If R is the sun, then have total eclipse with $F = 0$ for some finite time.

5.3 Geometric relations

Define an "L-plane" that goes through the center of the OB and, is normal to the direction to the Sun, has its Y axis in the plane of the OB:EB mutual orbit, its +X away from the Sun and its +Z axis toward the right-hand mutual revolution axis. This plane contains the OB terminator.

The Sun is considered infinitely far away .

Define the "eclipse surface point" (ESP) as the point of interest on the surface of the EB at local hour H_C, and latitude θ.

For solar eclipses by Phobos on Mars, need to consider the radius of Mars as it is a significant fraction of the radius of Phobos' orbit. So, include these geometric relations in the code, they will be trivial for most objects. However, do not include the small variation through an eclipse of the relative angular size of Phobos and the Sun as seen from the surface of Mars, just use the sizes at the center of an eclipse.

The angular radius of the Sun is $\alpha = R_S/(H_U U)$ where R_s is the radius of the Sun (km), H_U is the heliocentric range in Astronomical Units, and U is the Astronomical Unit in km.

Bias at latitude θ is $b' = b + (R_E/R_O)\sin\theta$, assuming zero obliquity and EB pole normal to orbital plane.

Zenith angle of center of OB for an ESP at (H, θ) is $\cos z = \sin p \ \cos\phi$. (spherical law of cosines); where:
  Longitude from noon is $\phi = \pi(H/12 - 1)$
  Co-latitude of sub-OB point on EB is $p = \frac{\pi}{2} - \theta - \arctan(b' R_O/M)$
And this angle is static for synchronus satellite.

Half-extent of an eclipse in the Y direction in km, is:

$$y_h = \sqrt{(R_O + r_S)^2 - (b' R_O)^2} \qquad \text{and} \qquad \beta = \arcsin(y_h/M) \qquad \text{eq : beta} \tag{2}$$

At any time t from mid-eclipse, the center of the EB is at $y = M \sin\psi$ and $\psi = \frac{2\pi t}{P_O}$. The Y offset to the ESP is approximately $-R_E \cos\theta \sin\phi$, which is generally small; ?? .

Distance between center of OB and ESP is approximately $Q = M - R_E \cos(z)$ omitting terms on the order of $R_E \cdot \beta^2$, the R_E term is important only for Mars in the shadow of Phobos.

The apparent size of the Sun in this plane, as seen from the surface of the EB, is $r_S = \alpha Q$. There will be some eclipse effect if the bias $|b'| < (1 + r_S/r_O)$

Define the angle from noon: $\phi \equiv \frac{H-12}{12}\pi$ radians

Anomaly at the center of eclipse for ESP at Hour H.

$X = \sqrt{m^2 + R_E^2 - 2MR_E \ \cos\phi}$

$\psi = \arcsin(\phi \frac{R_E}{X})$

The general case, when R_O and R_E could both be a significant fraction of M, is a trigonometric mess. Real cases of interest in the solar system are:

"Lunar": satellites in shadow; then $R_E \ll M$, and can treat $Q = M$

"Solar": Earth or Mars satellites casting shadow. Only Phobos shadow requires considering the radius of the EB in distance Q, and then the OB is tiny.

At any time, the position of the ESP is $y = Q \sin\psi$ and $\psi = 2\pi t/P$ where t is time from mid-eclipse and P is the EB orbital period. Also, $\psi = 2\pi(J - J_C)/N_2$ where J is the c-time count and J_C is the c-time of mid-eclipse.

During or near eclipse, the Sun:OB center separation in the L-plane is [km]

$$d = \sqrt{y^2 + \underbrace{(b'R_O)^2}_{\text{BIKM}}}$$

Eclipse is symmetric about orbital angle of $\nu = \pi$ but the eclipse function must be centered about ESP at the satellite surface hour requested.

In the KRC diurnal system, if surface point of interest is at hour H_c when the middle of eclipse occurs, and there are N2 time steps in a sol, with the last at midnight, then fractional (1-based) indices at the beginning and end of eclipse are $\left(\frac{H_c}{24} \pm \frac{t_h}{\text{sol}}\right) N_2$.

[V 3.5.4 did not handle a sol different from P, but 3.5.5 does.]

To allow any resolution in the satellite surface position, KRC uses fractional orbit angles that are on the time grid, but shifts application in TLATS or TDAY by integral time steps.

5.3.1 Lunar eclipse

For an eclipse with zero bias, the transition to totality, as a fraction of the orbit period, is α/π. In these units, the full eclipse lasts $(r_o + \alpha)/\pi$. For Europa, the values are roughly 1/3500 and 1/30. Thus, to begin to resolve the penumbral phase would require N2> 7000.

For a synchronous satellite, the half-time of an eclipse is $t_H = \beta P_O/(2\pi)$ days, where P_O is the co-orbital period (presumed small compared to the planet year). The half-time in KRC normal time-steps is $H_L = N_2 t_H/P_S$ where P_S is length of a sol; thus in this case $H_L = \beta N_2/(2\pi)$.

5.3.2 solar eclipse

When a satellite casts a shadow on a planet, the planet rotation period must be considered. Eclipse half-duration if bias=0: $t_H = y_h/(v_2 - v_1)$ where surface velocity is $v_1 = 2\pi \cos\phi \cos\theta R_E/P_S$ and the shadow velocity is approximately $v_2 = 2\pi M/P_O$.

The half-time in KRC normal time-steps is $H_S \equiv N_2 t_H/P_S$

For Phobos shadow on Mars, the full eclipse lasts less than a minute, so a typical $N_2 = 1536$,would be un-workable. Thus, need much larger N_2 or process the eclipse indices as real values and use a fine-layer factor of at least 4 to get about 20 fine-time points through an eclipse.

5.4 Implementation

In general, for any eclipse, set N24 as large as allowed (MAXNH=96).

To deal with rapid insolation changes, shorten the time-steps by some factor. Do not need to change the layering for stability, but should change it for responsiveness. To keep same stability factor, divide each layer by integral factor f and increase the number of times/day by f^2.

To resolve the penumbra stage, there should be several time steps within it; if this is impractical, there should be many (more than a dozen?) time steps within the entire eclipse.

Ideally N2 would be roughly length-of-a-sol / 2t, where t is the time for the satellite orbital phase to change by the angular diameter of the Sun θ_S . $t = P\ 2\alpha/(2\pi)$ where P is the satellite period (seconds) and N2= $P/t\ = \pi/\alpha$. E.g., for Jupiter, N2 (min) is 3515

Daily: Handle entirely in Tlats, with consideration for the large N2 required to see the shape of insolation through an eclipse.

.

Planet thermal load into new array: PLANH, compute in TLATS
Planet reflected solar load into new array: PLANV, compute in TLATS.
For daily eclipses, these are incorporated in TDAY, see Eq. 10
For rare eclipses, TFINE combines the two and does linear interpolation to fine time.

Satellites are assumed synchronus. Yet, both PERIOD and PARC(4) must be specified and should be the same.

5.4.1 Vector geometry

The coordinate system used by TLATS is the "Day" system
+Z toward body right-hand spin axis (north pole),
+X in the true solar midnight meridian,
+Y is Z cross X, and is in the equatorial plane
Sun at declination δ at midnight: $M = [\cos\delta, 0., \sin\delta]$
Sun diurnal progress is left-hand $\phi = -\frac{2\pi}{24}t$ where t is in hours, rotating around +Z
Local surface normal at latitude θ, in the noon meridian: $F = [-\cos\theta, 0, \sin\theta]$
To get the normal to a surface with slope (dip) β facing toward azimuth ψ measured east from North:
rotate F around +Y by β , generates temporary vector Q
then rotate Q around the original F by $-\phi$ to get tilted surface normal T

For an ESP at hour H_C, $\omega = \pi H_c/12$ a planetary heat source above the equator at noon would have a unit vector $P = [\cos\omega, \sin\omega, 0]$

5.4.2 Time indices for eclipses

Time indices passed between routines are always in TDAY units, in some places called coarse time or ctime. Where they are converted to/from fine-time (or ftime), they are treated as refering to the start of a time interval, before the diffusion calculation.

KRC time indices refer to the END of the interval they represent. Thus the Hour of an index is 24.*j/N when N is the number per sol. Insolation for index j is computed at the middle of an interval; i.e., the rotation angle is $\frac{j-.5}{N}2\pi$ from midnight.

ECLIPSE and TFINE are the only FORTRAN routines that deal with fine-time, however, transfers in/out of these routines use TDAY units; N2 per sol. The same hour and insolation conventions as above are used for fine time. See Figure 1 . For fine-time eclipse calculations, the origin is reset to J7 and the geometry calculations are done at the center of each fine interval.

ECLIPSE calculates the time of first and last contact in floating-point ctime; first contact is rounded down to JBE(3) and last contact is rounded up to JBE(4); JBE is passed between routines; the rounding ensures that the indices in JBE capture the full optical eclipse. ECLIPSE returns an array for the insolation factor FINSOL; the fraction of insolation that makes it past the occulting body to the Eclipse Surface point (ESP). FINSOL is 1 outside the eclipse.

Hour H of insolation calculations in 1-based indices
Coarse time: $H = (J - \frac{1}{2})\frac{24}{N_2}$.
Fine time: $H = J_7\frac{24}{N_2} + (I - \frac{1}{2})\frac{24}{KN_2}$ where K is the fine-time factor.

Radiation values at the center of fine-time intervals are computed by linear interpolation, but ctime pair interpolated switch at the middle of each ctime interval.

The TFINE routine continues grid calculation beyond J8=JBE(4) by an amount of time equivalent to J8-J7 to cover the thermal response to the possibly-rapid insolation changes near the end of eclipse.

5.5 Eclipse Specification,

Eclipse specification:
1: Eclipse Style: 0=none 1=Daily 1.3+=rare, round of value is layer factor

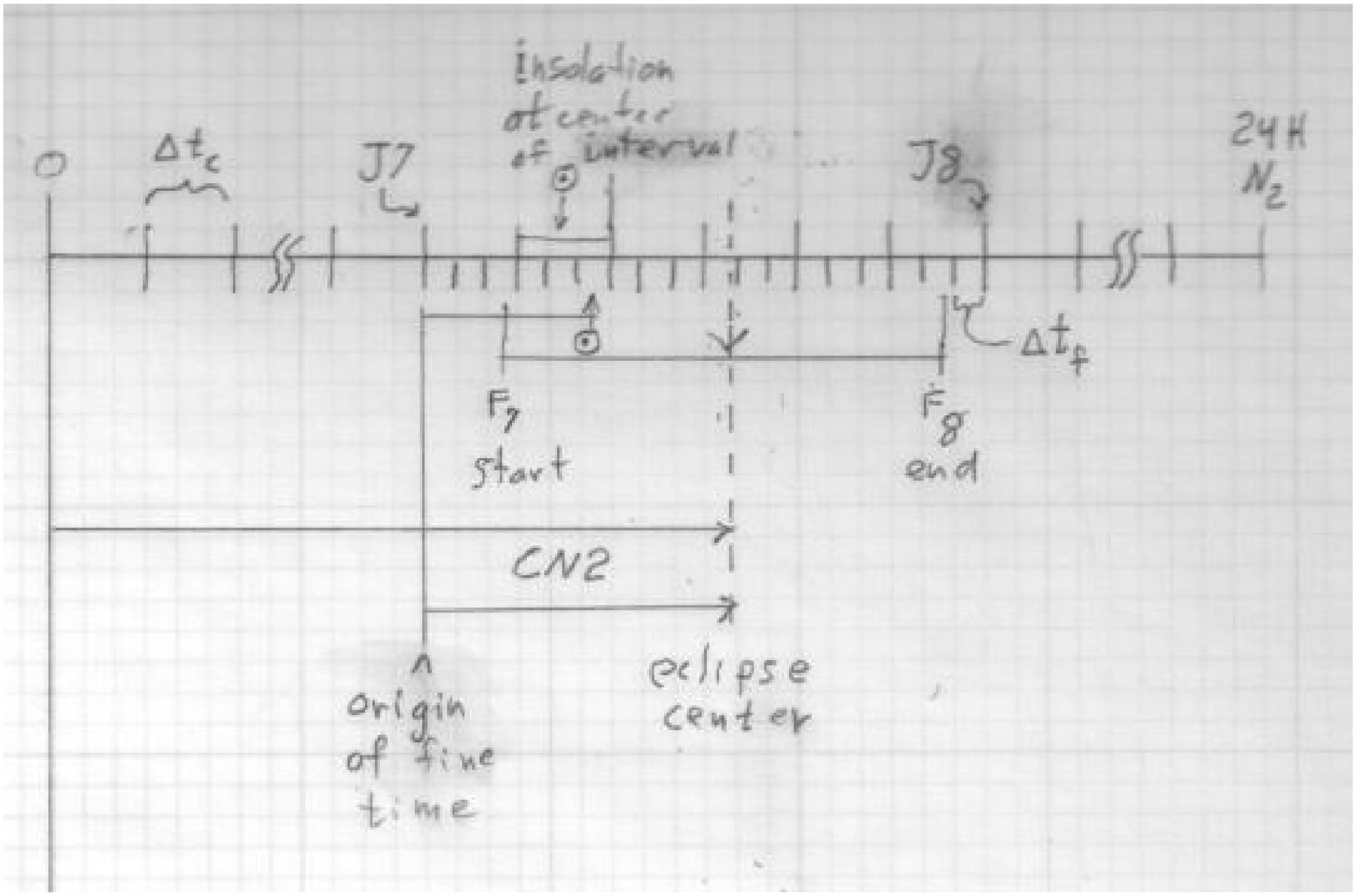

Figure 1: Time of day runs from midnight to midnight. The center of an eclipse is real index CN2, with the first and last contact at F_7 and F_8, all expressed in coarse-time units; these last two are rounded out to J7 and J8. The circle-dot symbols indicate the times of insolation calculations. The upper CN2 line is in ctime units; the lower in ftime units. Ftime index I=0 at the end of a ctime interval and I= tindex.png

Time factor is square of layer factor to retain stability

2: Distance to sun, AU (used to get Sun angular diameter)
3: Occulting body (OB) radius, km
4: Mutual center-of-mass orbit radius, km = M
5: Eclipsed body (EB) surface radius, km
6: Mutual solar synodic period, days
7: Eclipse Bias
8: [J2000 date of Rare eclipse] Assumed to be on the last “season”
KRC 3.5 uses the sign as a flag for base treatment. + is maintain heat-flow - is maintain temperature.
9: Eclipse central hour
10: Debug code. ne.0 prints constants and > 1 prints one point,
Negative runs a “ null eclipse” test mode in which the OB is considered transparent.
11: Current latitude on EB, degrees [replaced by TLATS]
12: Solar period of the EB [replaced by KRC]
x: Extinction scale height of OB’s atmosphere, km. NOT implimented

These will be input as a change line 14: first real value being non-positive means turn off. Typical input line:

14 1 5.2026 71492. 0.6711D6 1560.8 3.551 0.01 6000. 12. 2 77 77 / Europa

The latitude on the EB affects the bias b' and hence the timing of the eclipse so that ECLIPSE must be called for each latitude in KRC. When the OB is smaller than the EB, only a narrow range of latitudes can have eclipses.

5.6 Eclipses: Daily

For “Daily” (typically long) eclipses, fine-time is never used; the user can set N2 as large as they want to get the eclipse details. FINSOL covers the entire day in ctime steps; it is unity outside ot the JBE range.

Binary output files are the same as earlier versions of KRC.

5.6.1 Details

TLATS: Handles only daily eclipse: Sets LECL flag if PARC(1) $0.8 < x < 1.2$. If set, then
  Calls ECLIPSE once per latitude, which generates FINSOL insolation factor for each time-step
    and duplicates as SOLAU the variable for solar flux at current AU
  Each time step, multiplies the solar insolation by FINSOL(JJ)

TDAY: No change for daily eclipses.

5.7 Eclipses: Rare

For “Rare” (typically short), the uses specifies a fine-layer factor K_L (rounding the eclipse “style” parameter); the fine-time factor K_T is the square of the layer-factor. FINSOL covers in fine-time steps from the beginning of ctime JBE(3)+1 to the end of JBE(4).

Because of the rapid changes that can follow the return of sunlight at the end of eclipse, the detailed calculations of TFINE are continued for the number of ctime steps of the optical eclipse (at least one) KRC output interval after last contact. ???

5.7.1 Details

To ensure catching all the eclipse effects, expand the fine-time range by one earlier TDAY timestep and later by the duration of the eclipse JBE(4)-JBE(3); TDAY switches to and from TFINE before the diffusion loop. TFINE uses linear interpolation of upper boundary conditions to fine time-steps.

In TFINE, as in TDAY, the surface temperature is stored in layer index 1, but that layer is reconstructed as the virtual layer in each time-step.

TFINE is a modified copy of TDAY, with a single “day”. It increases the layer and time resolution, interpolating in time and depth as needed, then steps through the eclipse. It calls ECLIPSE to get the detailed obscuration profile.

Number of fine layers: virtual layer + (number of physical TDAY layers * layerFactor)
  N1F=1+(N1-1)*KFL and must store one more for the base

. LRARE is normally False. and TDAY(1 normally sets switch trigger JSW=-1
- If PARC(1) is $\geq$1.3 then TDAY(1 sets flag LRARE True and will do a RARE eclipse. It calls ECLIPSE to get JBE which contains the ctime steps before and after the eclipse. It calls TFINE(1 to do all that can be done without having layer temperatures.
- The eclipse is entirely within ctime JBE(3) to JBE(4), which could be the same for a very short eclipse.
- In TDAY(2 day loop, if LRARE, then on the last season, at the start of the last day, TDAY(2 sets JSW to JBE(3)+1 .
- In TDAY(2 time loop, when JJ equals JSW, if JSW = JBE(3)+1, TDAY transfers the layer temperatures to TFINE.
- TFINE executes 2(JBE(3)-JBE(4)) ctime loops
- After TFINE returns, TDAY sets JSW equal to the end of eclipse followon and proceeds normally until the (JJ equal JSW) test is again satisfied, when (before diffusion) it sets the temperature profile to the final from TFINE, and finishes the last day normally, leaving a discontinuity in temperature at the end of the eclipse. TFINE has a large storage buffer, and for each rare eclipse case stuffs the eclipse factor and temperature profile (up to MAXKF=20 fine layers) into this for writing to a .bin5 fileThis file covers every ftime step computed.

The output file is always named “<input file name>tfinexx.bin5” where xx is the case number.

Eclipse length of MAXN2 or more ftime steps, or eclipse that reaches midnight (theoretically possible at high latitudes) will cause an error.

5.7.2 Extra printout

Rare eclipse cases put additional material in the print file, apart from debug options. Below, left-adjusted lines are example printout and inset lines are explanations.

.

TFINE IQ,J4= 1 2
    IQ is the TDAY action requested: 1=setup, 2=do the time and layer loops
    J4 is latitude index; not reliable or relevant for IQ=1
TFINE layers: Num,lowest center[m] 82 0.8995
    TFINE(1: the number of fine layers, including virtual. Depth to the center of the lowest (not base) layer
Min safety: layer,factor= 1 0.000 0.000
    TFINE(1: Minimum convergence safety factor: layer, factor,
TFINE low lay of time doubli: 12 20 27 34 42 49 57 64 72 82
    Deepest layer for each fine-time doubling
-777 3 10 2 4 760 776 792 82
    TFINE(1: tag, NCASE, J5, J4(+1), J3, JBE(3:4), J9, N1F, LATOK
TFINE exit   notification of exiting TFINE
TFINE IQ,J4= 2 1

TTJ(1)... 260.19471582799264 258.02291589626202 -0.0000000000000000
    Virtual layer T for TDAY and fine layer system. Delta T at fine base
LZONE,LALCON,J5, IK1:4= F T 10 0 0 0 0
    In TDAY(2: last 4 are the T-dep. layer specifications.
TFINE: Case= 3 JJJ= 3 83 306 1 0 0 0 5 80 0
        JJJ is the set of 10 integers given to BIN5F
TFINE wrote tfine03.bin5 iret= 0
TFINE exit
End eclipse: JJ,KG,delT,delE 793 28 0.63383E-01 8067.1
    KG is the lowest TDAY layer represented in the fine layer system
    delT is the T discontinuity of the lowest TDAY layer at end of eclipse
    delE is the delta thermal energy in the lowest TDAY layer at that time.

6 TFINE

TFINE interacts primarily through the many KRC common's. Subroutine arguments are used to transfer in:
    the stage index: with value 1 or 2
    the physical properties of each layer.
and transfer out:
    the coarse layer temperatures after eclipse
    the number of reliable output temperatures, or a negative values indicating an error.

The initial call to ECLIPSE returns the last original time step before the eclipse starts and the first after it ends. When TDAY on the last day of convergence reaches the starting time step, it calls TFINE which proceeds through all of its time steps and returns the temperature depth profile that it gets, TTF, which is remembered by TDAY. TDAY proceeds with its normal calculations until it reaches the time step after those covered by TFINE, when the temperature profile is reset to TTF, and TDAY runs through the rest of the last day.

TFINE ignores any atmosphere, except for any effect TLATS may have included on collimated insolation. It does handle far-field radiation.

There can be a small non-physical effect if the number of finer layers 1+(N2-1)*PARC(1) would exceed the firm-code size MAXFL. The bottom of the fine system is considered insolating during the eclipse, whereas the normal interface at that depth would be conducting. The non-physical change in system energy is roughly $B_j \rho_j C_j \Delta T_j$ where the last term is the amount that the temperature of the deepest original layer treated by the fine system j is changed at the end of the eclipse.

Note that continuation to another season using the asymptotic predictor would be inappropriate after a "rare" eclipse.

The temperature gradient that existed in the TDAY system at the depth of the bottom of the TFINE layers at the start of the eclipse is held constant at the bottom of TFINE through the eclipse.

$$\nabla T = \frac{T_{j+1} - T_j}{(B_{j+1} - B_j)/2} = \frac{T_{i+1} - T_i}{(B_{i+1} - B_i)/2} \tag{3}$$

where the i subscripts are for the TFINE values at it lowest two layers and the j subscripts are for the TDAY layer values at the corresponding depth. Thus

$$T_{i+1} = T_i + \underbrace{(T_{j+1} - T_j)\frac{B_{i+1} - B_i}{B_{j+1} - B_j}}_{delbot} \qquad \text{eq : tbot} \tag{4}$$

When TFINE starts an eclipse period , it uses cubic spline (or linear) interpolation with natural boundary conditions (zero 2nd derivative at top and bottom). To avoid interpolation failure, all fine layer centers must be within range of the TDAY layer centers; thus maximum I is $K(N_1 - 1) + 1 + K/2$.

6.1 Details

Design with two sections, similar to TDAY. TFINE(1 does everthing that does not require the starting temperature profile of the time-dependent radiation field. TFINE(2 does the timesteps.

Has access to commons
Creates finer layers and has an inner timeloop for the finer time steps.

Needs the original center depths of each layer, and must generate the center depths of the new layers for interpolation and the bottom depths for the diffusion equations.

Anything that is defined in TDAY (vrs defined in commons) is not available in TFINE unless an argument.

Zone table logic is complex, could duplicate them in TFINE but better to pass in as arguments the ultimate products: KTT, DENN, CTT as arguments; TTJ, XCEN and BLAY are in common

Each TDAY layer of thickness B_j is divided into K layers with thickness $B_i \equiv B_{j_k} = f_i B_j$

K fine layers must have a geometric ratio r that yields the same full-layer ratio as $R \equiv$ RLAY.

$$r^K = R \qquad \text{or} \qquad r = \exp\frac{\ln R}{K} \qquad \text{eq : rk} \tag{5}$$

and the sum of f_k must be 1.

The sum of a geometric series of ratio r, first term 1 and n terms is

$$S \equiv \sum_{j=0}^{n-1} r^j = \frac{1 - r^n}{1 - r} \qquad \text{eq : sumr} \tag{6}$$

$$f_1 = 1/S = \frac{r - 1}{r^K - 1} \Rightarrow \frac{r - 1}{R - 1} \qquad \text{eq : f1} \tag{7}$$

and $f_i = r f_{i-1}$

Each time-dependent input is linearly interpolated to the fine-time steps:
- ALBJ Surface albedo, which may vary with incidence angle
- ASOL Collimated flux onto (sloped) surface
- FARAD Far-field radiance
- SOLDIF Diffuse solar flux
- ϵ PLANH + $(1 - A_s)$PLANV absorbed Planetary flux

TFINE always writes to print file
- Number of fine layers and depth[m] to center of deepest layer
- If any T-dependent layers, the first and number of the A and B layers
- Low layers for fine-time doubling
- -777, Indices for: case,season,latitude,converg.day, eclipse hour range ...

Layers temperatures j returned by TFINE, after TSUR as the layer (1) the rest of the layers are from the fine layers i. This could be based on:
- if K odd, $i = jK - 3(K - 1)/2$
- if K even, average of layers $i = jK - 3K/2$ and $i + 1$

However, simpler (and better for even K) to use spline interpolation.

7 Planetary fluxes

For synchronous satellites, the temperatures depend strongly on longitude but KRC version 3.5 does not treat longitude explicity. For the side facing the planet (the "near-side"), the peak reflected radiation comes at midnight and eclipses come near noon. For the side away from the planet, there is no reflected or thermal planetary heat load and no eclipses.

Since there are two bodies in addition to the Sun, must treat the effect of solar reflection and thermal emission from the "planet". Version 3 will assume these are sinusoidal with orbital phase. E.g., in the form $F = c_1 + c_2 \cos(\nu - c_3)$ and in units of W m^{-2}. Orbital longitude ν is zero when the satellite is at inferior conjunction as seen from the Sun (is this the general convention?).

7.1 Planetary Flux specification

Solid angle of OB from EB is approximately $\pi\beta^2$ where $\beta = \arctan(r_O)$; exact is $\Omega = 2\pi(1. - \cos(\beta))$

Must specify 7 values:

1: Average thermal flux from OB (planet) at the EB (satellite) Wm^{-2}
2: half-amplitude of variation with phase
3: Phase lag, in degrees from peaking at OB sub-solar meridian.
4: Average solar flux from OB at the EB Wm^{-2}
5: half-amplitude of variation with phase
6: Phase lag (as above)
7: The longitude (in Hours) of the EB surface point.
Zero is opposite the sub-OB point; the sub-OB point is at 12.

These will be input as a change line 15: the first real value being non-positive means turn off.

Example:

```
15   0.156 0. 0.   0.464 0.464 0.  12. / Jupiter heat load on Europa at Sub-J
```

7.2 Zenith angle of occulting body at the eclipse point

??? MORE

7.3 Planetary load away from zenith

Assume the absorption surface is Lambertian. For a point source, the effect varies with zenith angle as $\cos z$. For a modest source of radius R radians whose center is at zenith angle z_1, the effect is

$$W(z_1) = \frac{\int_y^\pi \cos z \cdot 2R\sin\theta \; R\sin\theta \; d\theta}{\pi R^2} = \frac{2}{\pi}\int_y^\pi \cos(z_1 + R\cos\theta) \cdot \sin^2\theta \;\; d\theta \tag{8}$$

where θ is the angle around the center of source measured from the lowest point and y is the horizon limit of $\arccos\left((\frac{\pi}{2} - z_1)/R\right)$ if $z > (\frac{\pi}{2} - R)$ and 0 otherwise.

As $R \rightarrow 0$,

$$W \rightarrow \frac{2}{\pi}\cos z_1 \int_0^\pi \sin^2\theta \; d\theta = \frac{2}{\pi}\cos z_1 \coprod_0^\pi \frac{x}{2} - \frac{\sin 2x}{4}\Bigg] = \frac{2}{\pi}\cos z_1 \cdot \frac{\pi}{2} = \cos z_1$$

as expected. Here $\coprod_l^u \cdots]$ stands for evaluation at the upper limit minus evaluation at the lower limit

Expanding $\cos(z_1 + R\cos\theta) \Rightarrow \cos z_1 \cos(R\cos\theta) - \sin z_1 \sin(R\cos\theta)$ The form of the integral becomes

$$c\int \cos(a\cos x)\sin^2 x \; dx \;\; + \;\; s\int \sin(a\cos x)\sin^2 x \; dx$$

for which I could not find an analytic solution.

Numerical solution coded in IDL **planheat.pro**; see Fig. 2. For Europa, finite size makes at most 2% difference, and greater than 1% only when within 1.5° of the horizon. Until the lower edge of the planet nears the horizon of the satellite, the normalized factor is virtually constant; the effect is about 0.13% for Europa and barely 1% for a 0.3 radian source

Because the effect of a finite angular size is small, I elected to omit it for version 3.5; the influence follows the cosine of the incidence angle for the OB center onto the [tilted] surface, μ_P.

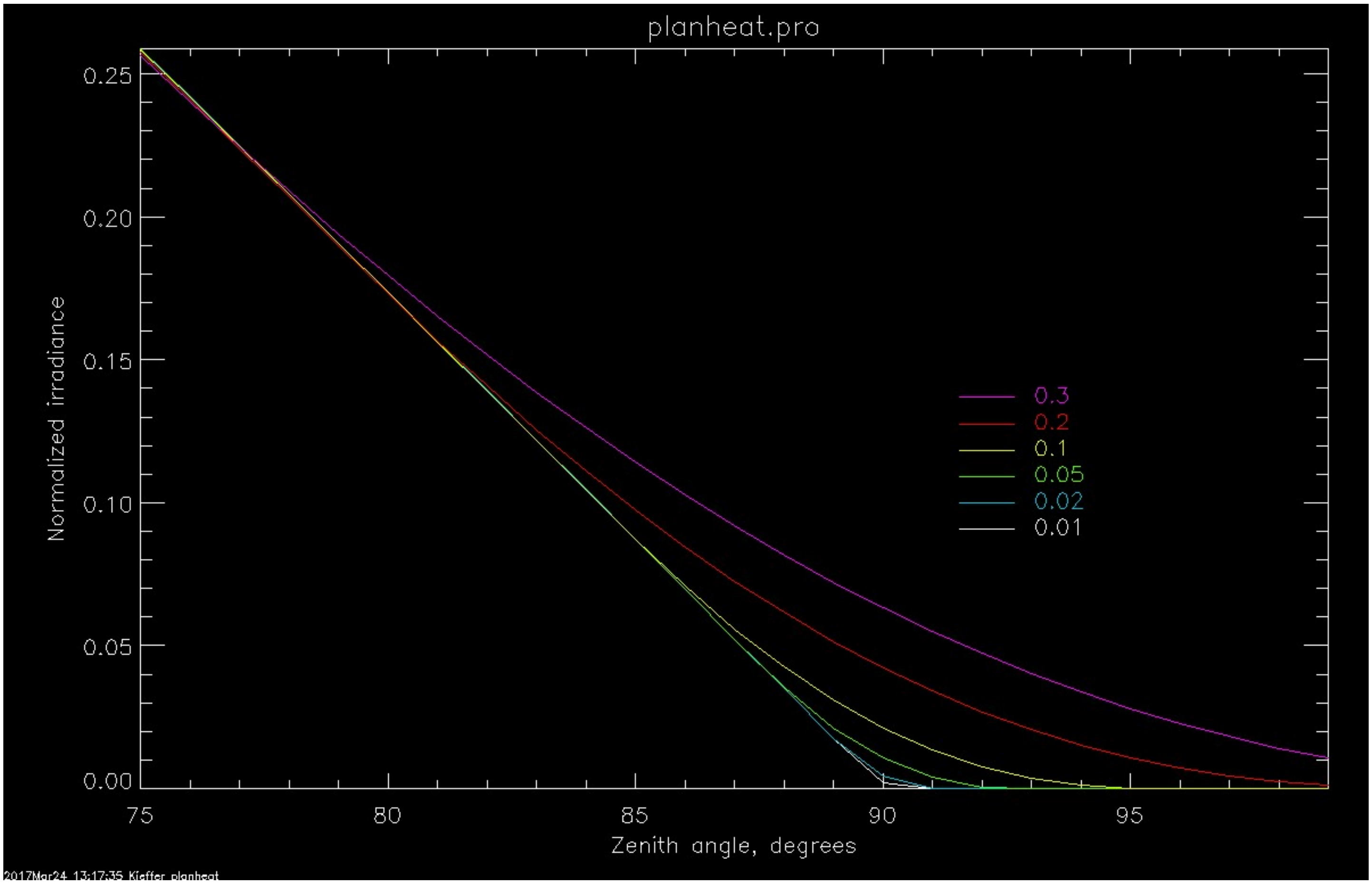

Figure 2: Normalized heat-load for finite-sized round sources as a function of zenith angle. Lambertian surface assumed. Legend shows the radius of the source in radians; for Europa the value is 0.1067. Infinitesimal source follows a cosine relation. Larger source are slightly less than cosine except near the horizon. planheatb.png

7.4 Static geometry for synchronous rotation

Only synchronous satellites are considered.

In TLATS, a planet source is assumed to be in the equatorial plane and above “noon” so that it has a fixed relation to the target (tilted) surface with cosine of angle onto tilted surface μ_P=COSP. IR and visual fluxes are initially set to zero for each latitude. If the logical flag LPH is True, then Planetary fluxes computed for orbital phase at each time-step and multiplied by $\mu_P \geq 0$.

In TDAY, if LPH is True, then both the plantary fluxes are multiplied by their absorption coefficents and added to the surface energy budget.

7.5 How it works

TLATS: Sets the flag LPH True if PARW(1) positive. At each time step, if LPH True,
sets PLANH(JJ)= $w_1 + w_2 \cos(\theta - w_3/\text{RADC})$ where RADC is degrees/radian.
add to the diffuse light SOLDIF(JJ) $w_4 + w_5 \cos(\theta - w_5/\text{RADC})$

TDAY: Sets the flag LPH in the same way as TLATS. At each time step, if LPH True
adds to the absorbed hemispheric downwelling IR flux ABRAD the amount FAC6*PLANH(JJ) where FAC6 is fraction of the sky visible times surface emissivity.

In version 355, TLATS computes the bias for each latitude on the EB.

Table 1: Europa run cases. Case 8 uses Jupiters polar radius and bias is near the maximum possible. The last two cases are physically impossible

Num.	name	slope	Jup. flux	Heat flow	eclipse hour
1	Base	0	0	0	none
2	Slope	30° NE	0	0	none
3	Flat	0	yes	0	none
4	P.Flux	0	yes	100	none
5	Daily PF+100	0	yes	100	12
6	Daily	0	yes	0	12
7	Daily 13H	0	yes	0	13
8	Biased	0	yes	0	12, bias=.63
9	Rare	0	yes	100	12
10	Rare:con	0	yes	100	12

8 Examples

Example runs for a few planet/satellite pairs were run; these input files are included in the distribtion

8.1 Jupiter / Europa

The results for sample input file EurH.inp are shown in Figure 3; the cases are listed in Table 1

Example runs were done with realistic conditions. E.g., for the sub-Jovian longitude on Europa, using the nominal values listed in §B with thermal inertia 200 in MKS and 22 layers to a total depth of 11.8 diurnal skin depths.

An eclipse of Europa with zero bias, on the equator, eclipse center at 13 H is shown in Figure 4. Although physically impossible, this "rare" eclipse demonstrates the high-time-resolution mode on a KRC eclipse run.

During development, many runs were done with all the eclipse debug options enabled, which generates 6 "fort.xx" text files; the results can be viewed using the IDL routine krv35.pro.

Some results are shown in Figures 6 and Figure 7. Some effect on Tsur of changes are shown in Fig. 5. With the values of *EurH.inp* (N2=6144), at the equator basal heat-flow of 100 mW/m^2 increases T about 0.5 K, and radiation from Jupiter increases T about 1.3 K.

To see the details of eclipse onset, cases were run in the "rare" mode (which never actually occurs for Europa), with a fine-layer factor of 3 which yields a fine-time factor of 9.

The surface temperatures for the two methods of handling the lower boundary condition for [impossible] Rare eclipses differ by $<$ 1 nK. The temperature jump at the lowest layer in common with TDAY and TFINE (layer 22, depth 0.67m or 11.1 diurnal skin depths) was 9 mK when the bottom of TFINE preserves heat flow and 11 mK the bottom of TFINE is held at a constant temperature.

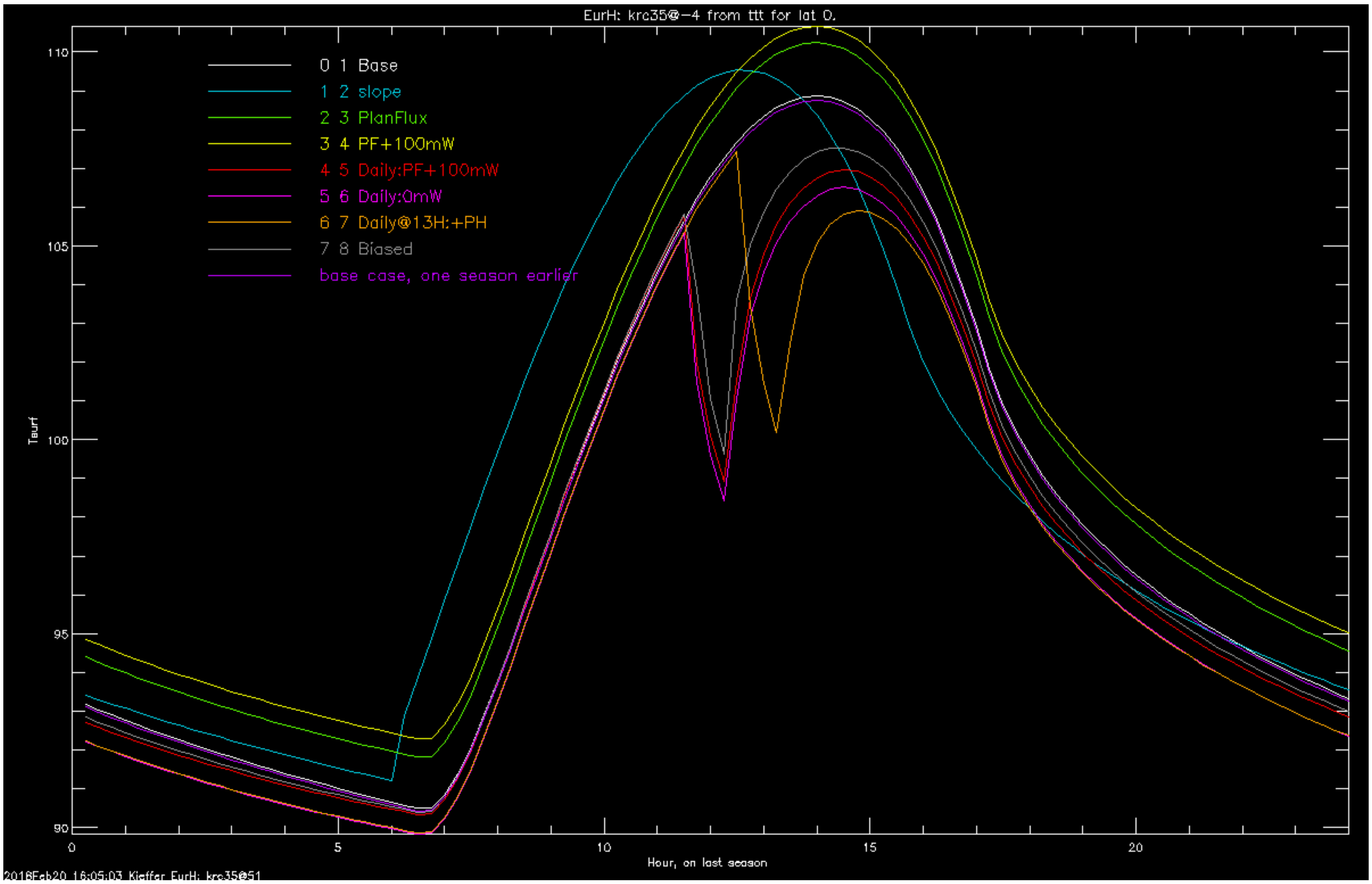

Figure 3: Europa diurnal surface temperatures at the equator using the *EurH.inp* input file; run used N2=6144. The 2nd column in legend indicates the case number. Temperatures from the *.t52* output file. The slope is dip of 30° toward northeast. EurH22.png

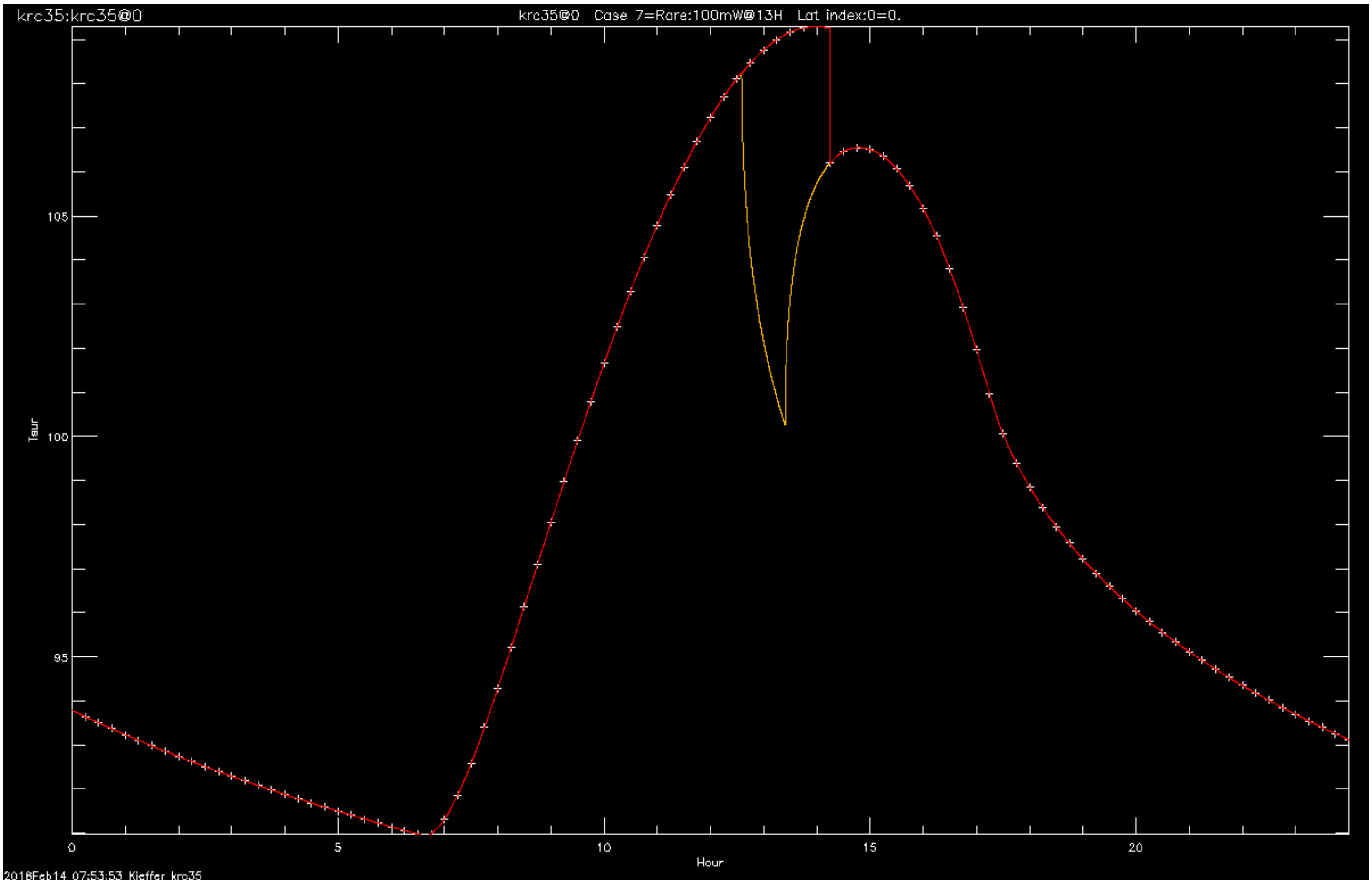

Figure 4: Diurnal surface temperature for Europa "rare" eclipse with zero bias, on the equator with eclipse center at 13 H.The plus signs show the points output in the normal .t52 file. Red line (6144 points) are from the *tout* file, orange line is from the *tfine* file (3835 points). EurGcase7.png

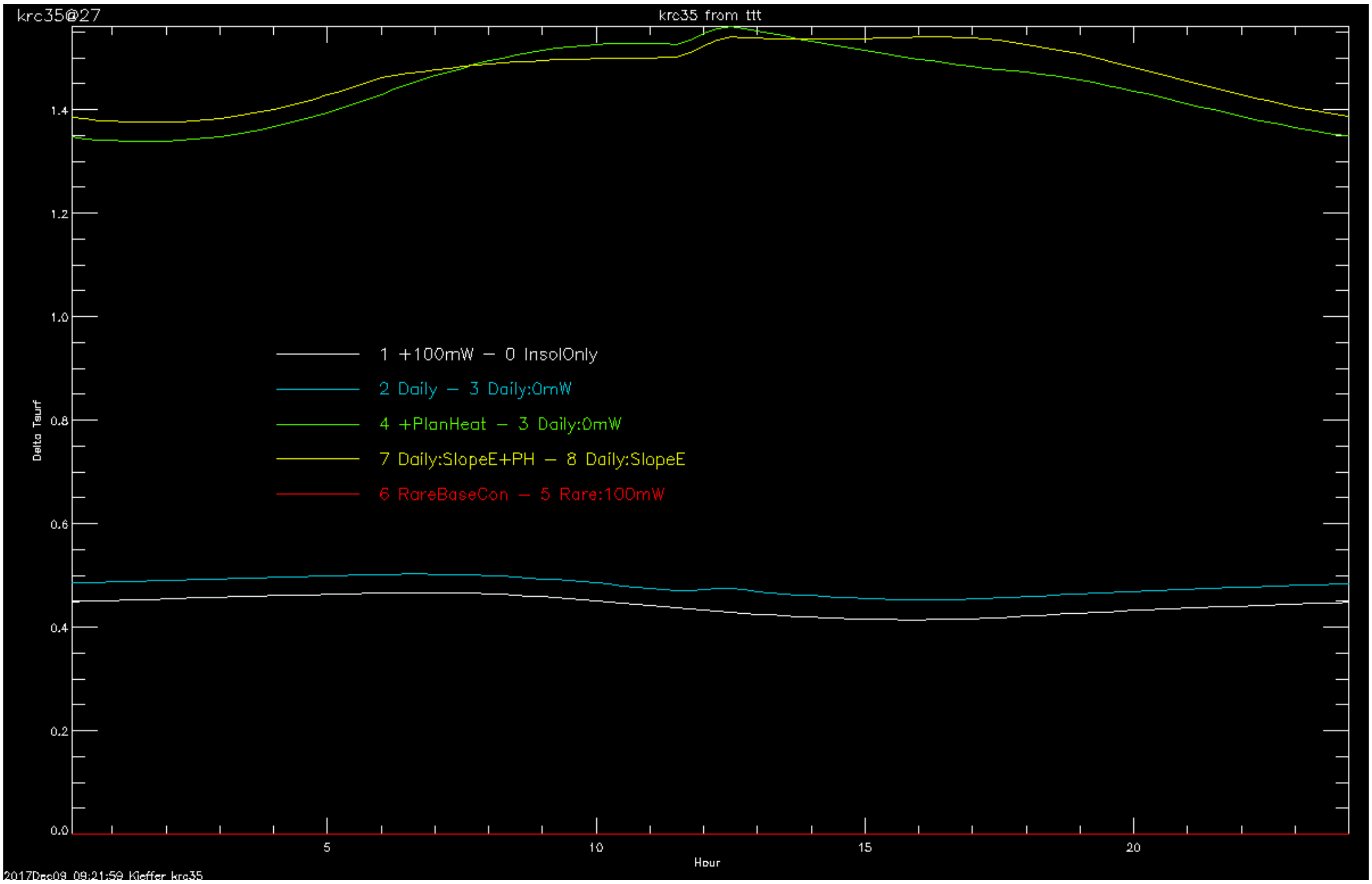

Figure 5: Diurnal change in Tsur for 6 case-pairs, for the last season. Blue and green show the effect of 100mW/m2 basal heat flow. White show the effect of the planetary flux. The effect to the two options for bottom conditions during eclipse is below double-precision roundoff except for the lowest layers. eurCD.png

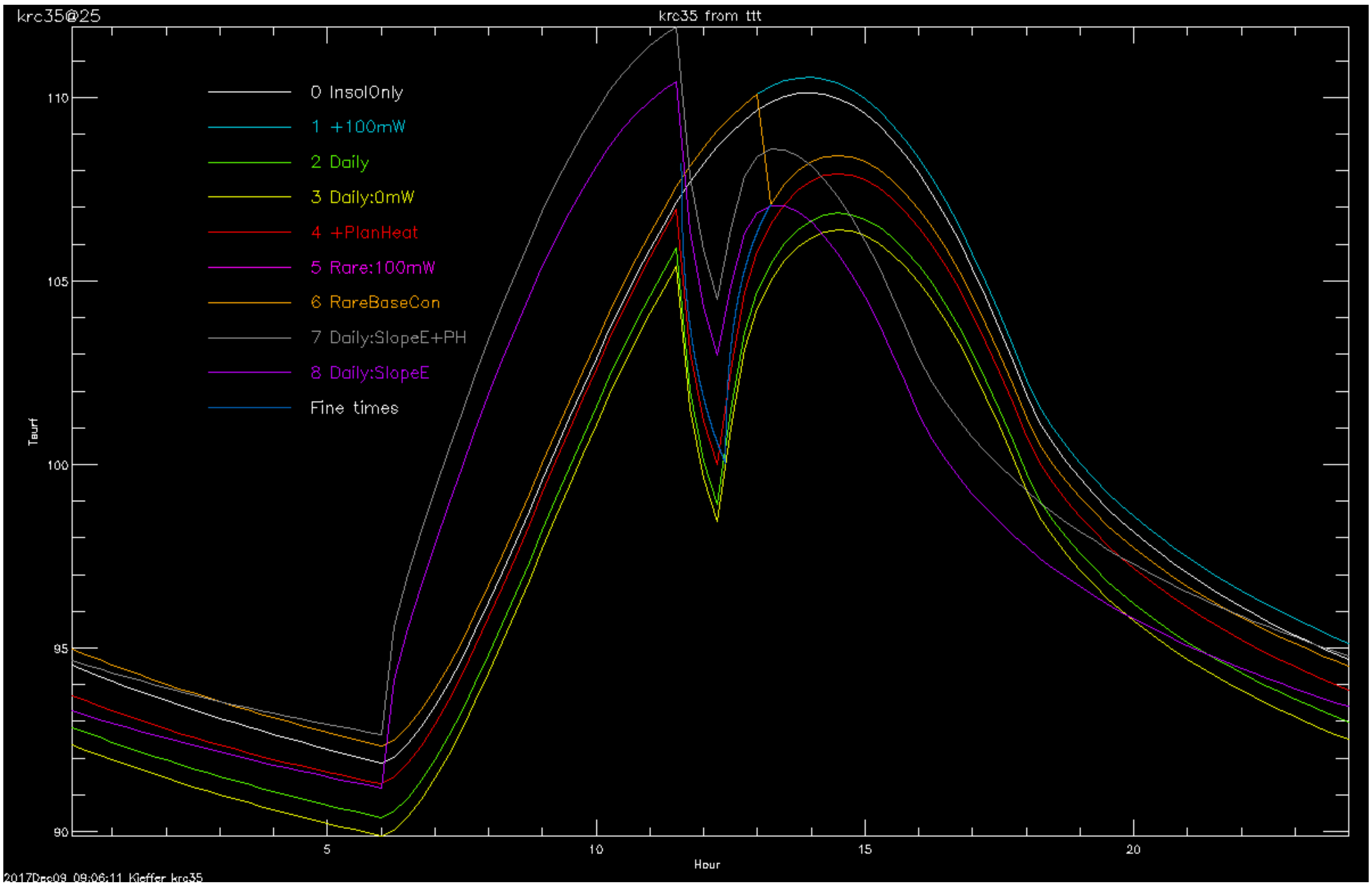

Figure 6: Europa surface temperatures for several conditions for the equator, with eclipse at local noon. Legend has an abbreviation for the conditions; see Table RUN for description. Input file eurF.inp . For "rare" sclipses, the .t52 file has surface temperatures which ignore the eclipse; the eclipse temperatures are in *tfinexx.bin5* where xx is the case number (1 larger than the values in the legend) these are shown as the lowest curve in the legend. eurFTs.png

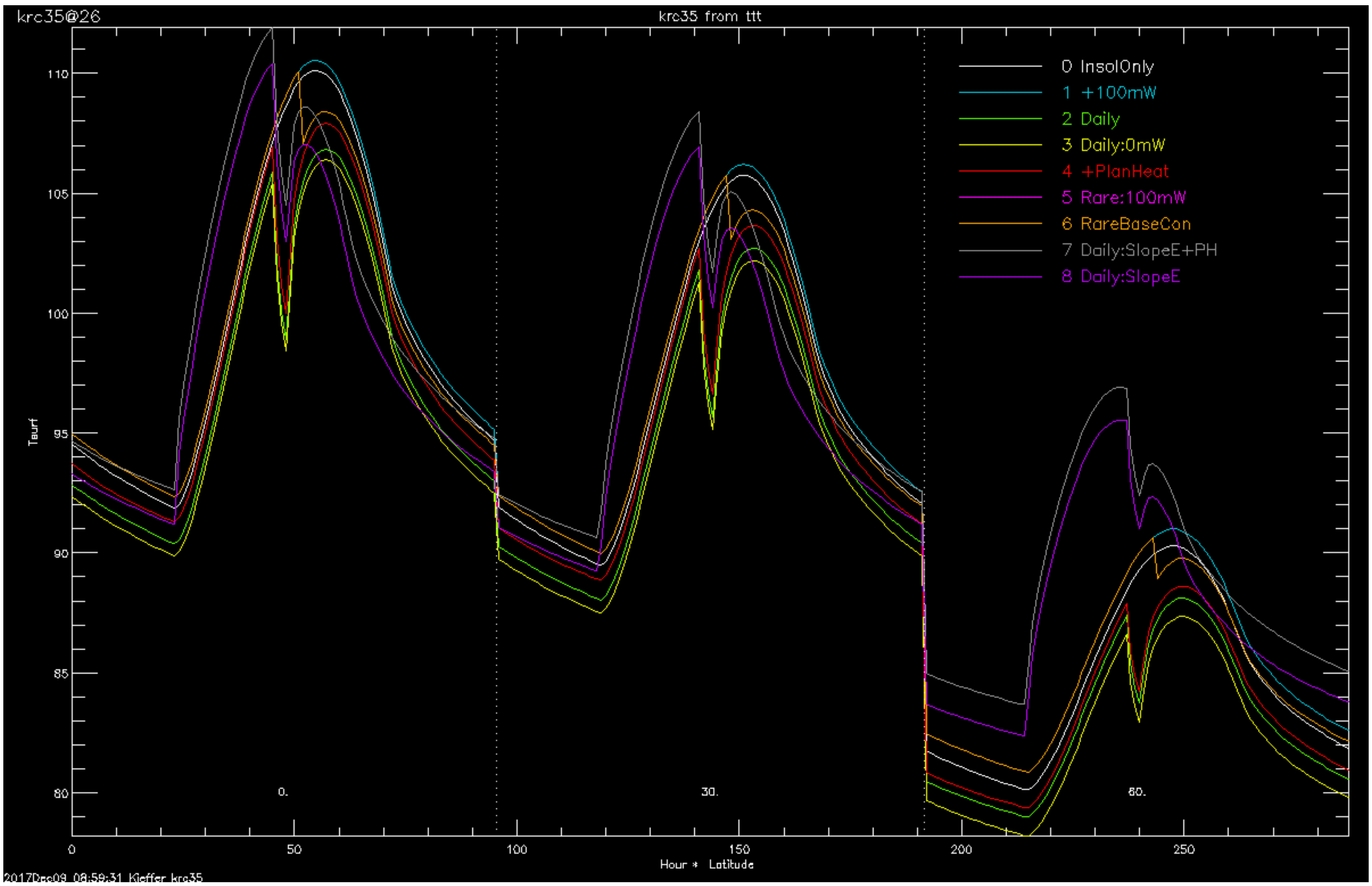

Figure 7: Europa surface temperatures for several conditions for latitudes 0, 30 and 60. Input file eurF.inp . See Table RUN for cases. eurClats.png

8.2 Mars / Phobos

For Mars/Phobos, with nominal physical properties for each, a "lunar" eclipse is shown in Figure 8 and a solar eclipse in Figure 9.

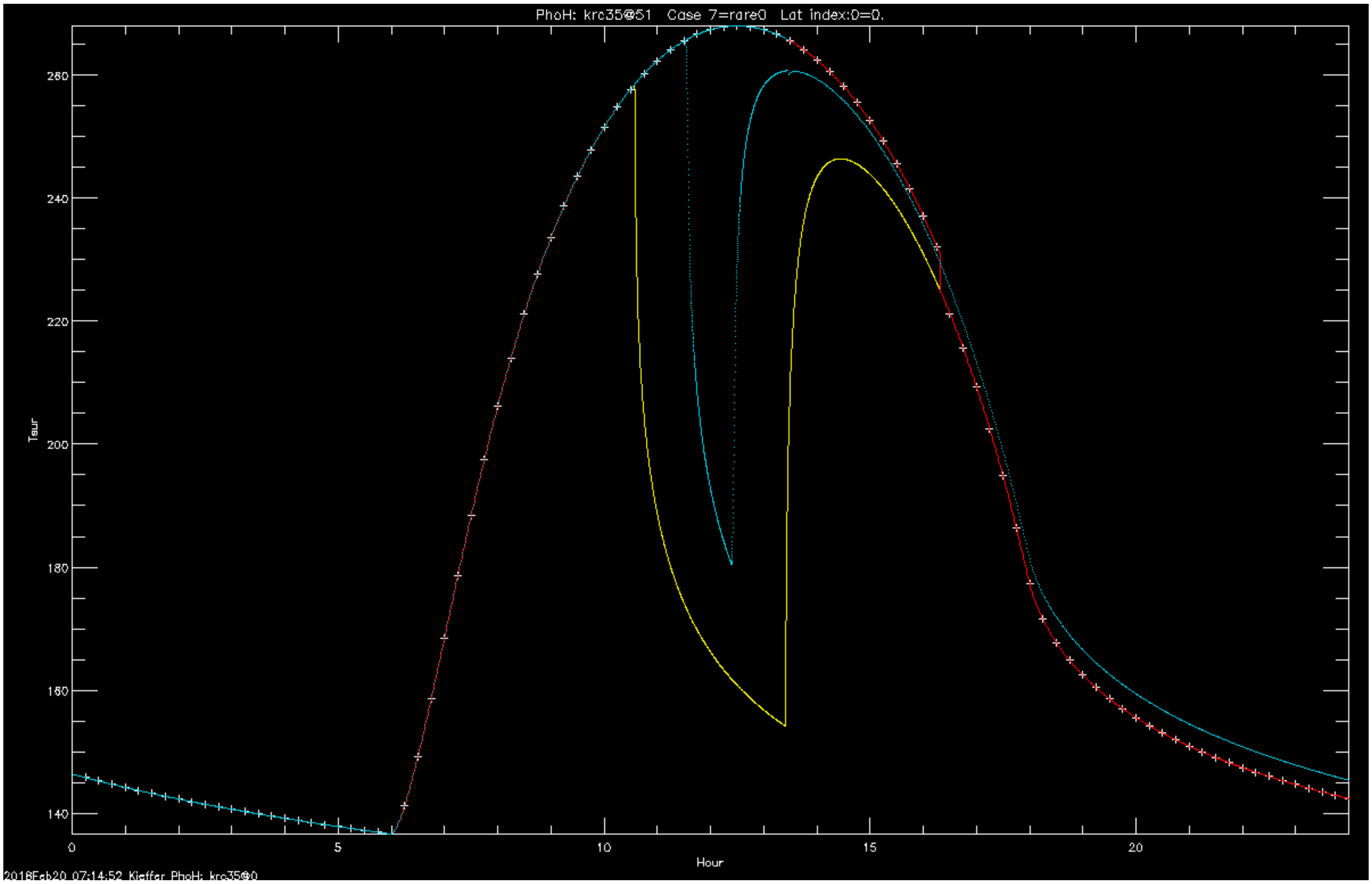

Figure 8: Phobos surface temperatures at the equator through an eclipse by Mars. The temperatures for a run with N2=1536 and no eclipse are shown in green (only 3 points). Normal *.t52* file results shown as white + sign. An eclipse with zero bias *tout* file as red dots.); the vlaues from the *tfine* file are shown in yellow. The results for a run with bias 0.95 are shown in blue. PhoLun.png

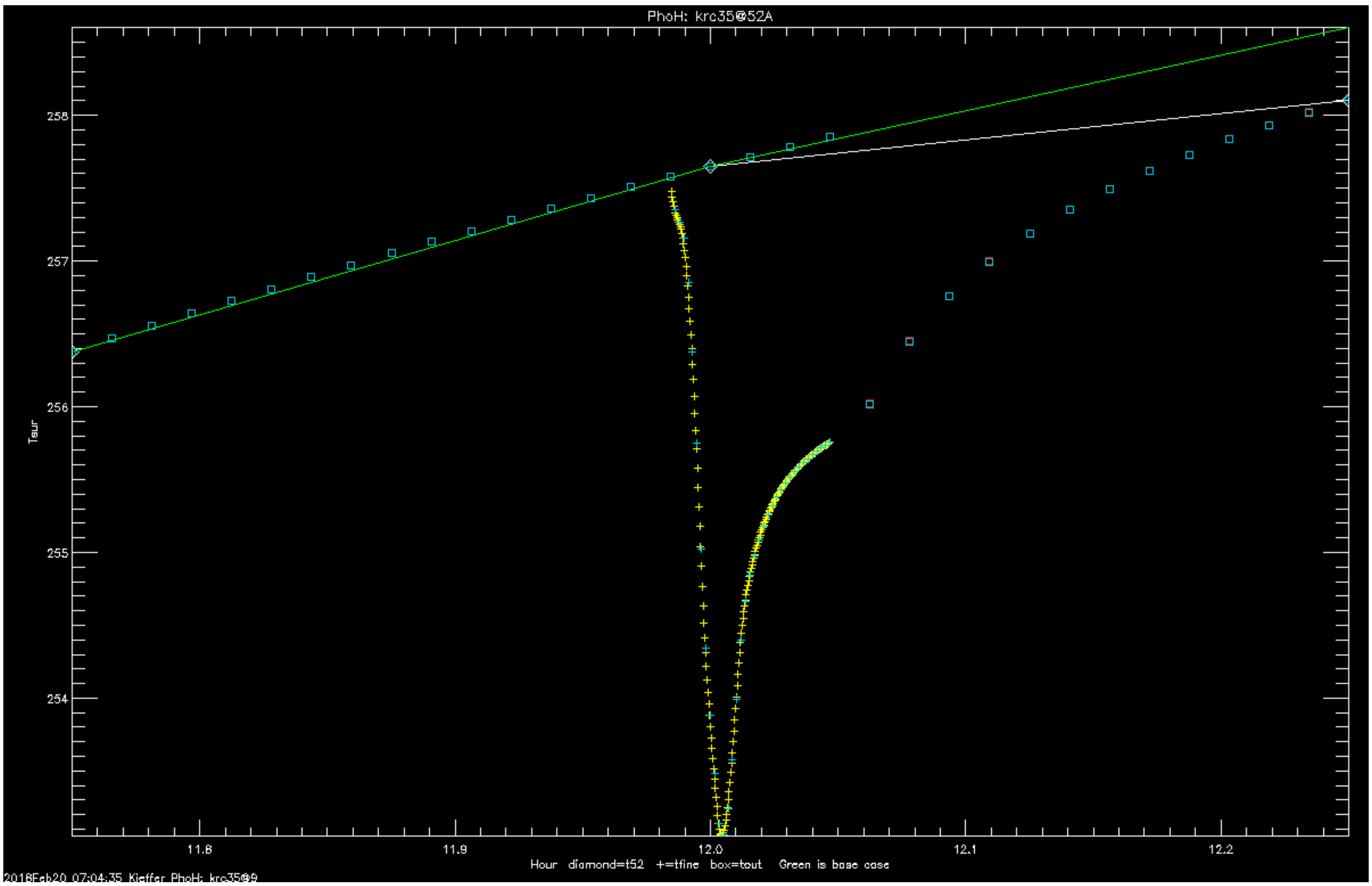

Figure 9: Mars surface temperatures at the equator through a solar eclipse by Phobos. Note the plot time range covers only 1/2 Hour. The temperatures for a run with N2=1536 and no eclipse are shown in green (only 3 points). For an eclipse with layer factor 7, the values at each time step (from the *tout* file are shown as red squares (mostly hidden); the values from the *tfine* file are shown as yellow + sign. The results for a run with layer factor 3 are shown in blue. PhoH54.png

8.3 Earth/Moon

Earth lunar eclipse runs are shown in Figure 11. The run uses nominal lunar surface properties similar to Hayne18=[1] surface, but homogenous with depth. Latitudes -60, -30, 0, +30 and +60° were run,. Cases are:

1: No eclipse
2: Add 20mW m^{-2} basal heat flow
3: Add Earth radiation
4: Same as case 3 with a lunar eclipse at noon and no bias
5: Same as case 4 with a bias of 0.5, so that Lunar latitude +60 is just outside the umbra
6: Same as case 5, but run in 'Rare' Mode
7: Same as case 6, except thermal inertia is 200.
8: Same as case 6, except Moons surface meridian is at 15 hours
9: Same as case 6, except using two zones of T-dependent material

Figure 10 shows the diurnal surface temperature variation for all cases

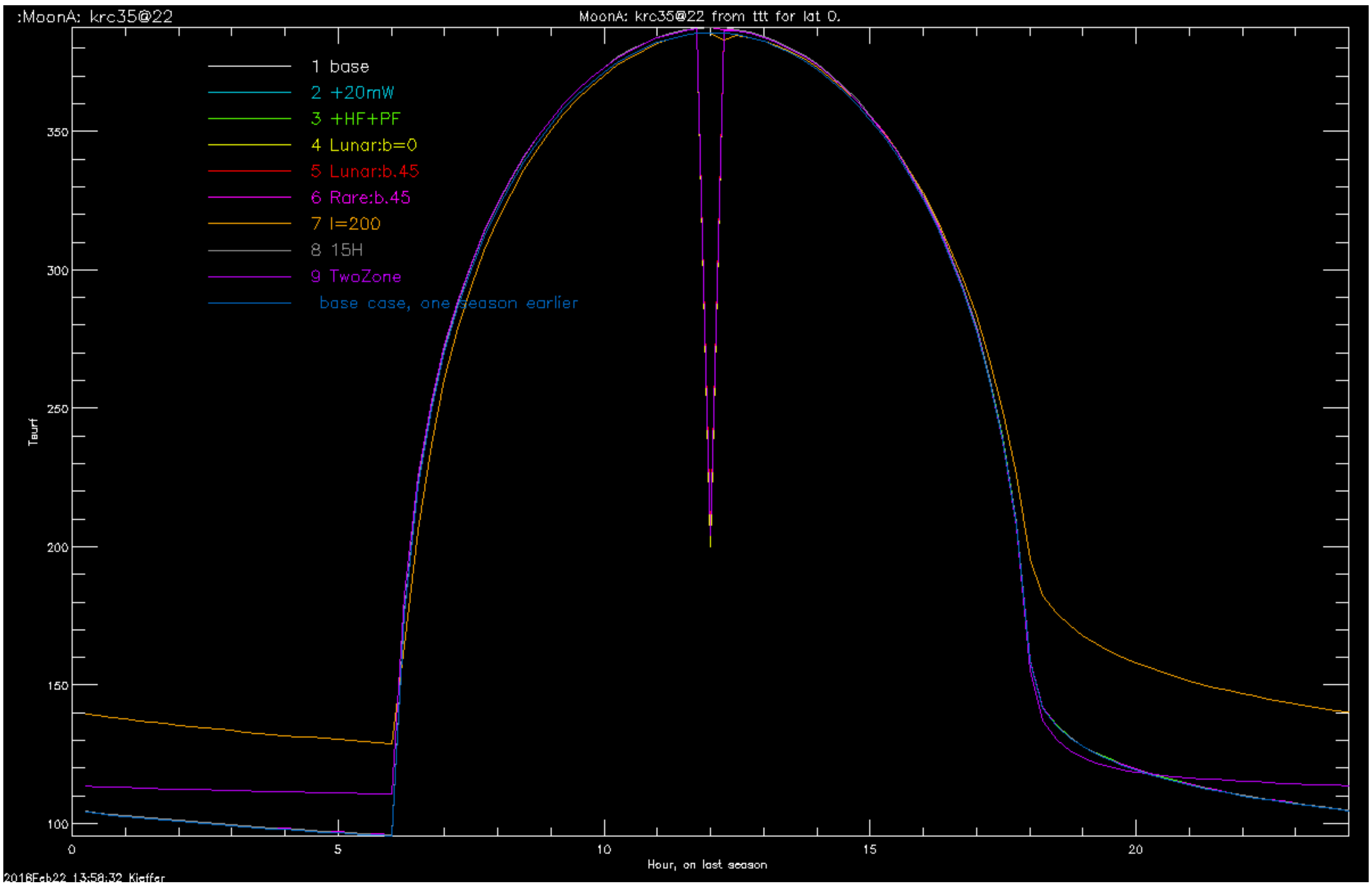

Figure 10: Diurnal surface temperature for all example Moon cases; case numbers in the first column of legend. In many cases, the changes are small and the curves are overwritten by latter cases; substantial changes occur for I-200 and Two-zones. Moon22.png

The effects of minor energy sources are shown in Figure 12.

A 2-zone case was created using Hayne18=[1] values at 1/4 and 3/4 of the way through their continuous density profile. The KRC layer table is below.

Figure 13 shows the change in diurnal surface Temperature from the homogenous case to a two zone case; lower zone starts at 0.0328.

```
 1.020E+06=Dens*Cp   2.908E-09=Diffu.      0.0486=Scale       55.00=Inertia
 Beginning at layer   7  At       0.0328 m.
 1.300E+06=Dens*Cp   5.385E-08=Diffu.      0.2091=Scale      301.66=Inertia
        ___THICKNESS____    __CENTER_DEPTH__  Conductiv. Density Sp.Heat     Total Converg.
```

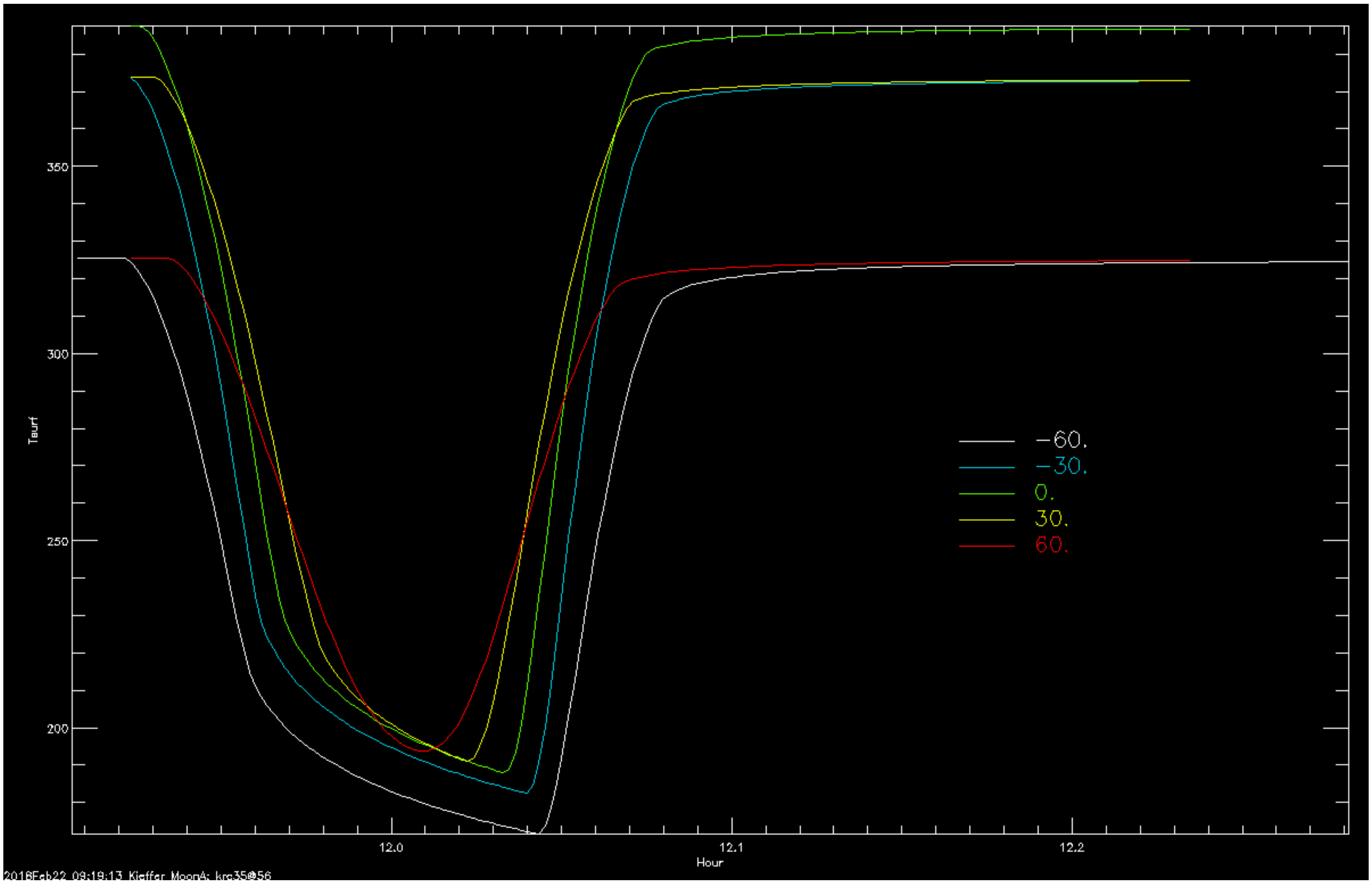

Figure 11: SUrface temperature through lunar eclipses using nominal homogeneous properties; input file *MoonA*; case 6. Five latitudes are shown, with curves covering the hour range of the *tfine* file. Because of the positive bias (+.5) totality becomes shorter to the north, and is not reached at 60N. Moon56.png

LAYER	D_scale	meter	D_scale	meter	W/m-K	kg/m^3	J/kg	kg/m^2	factor
1	0.0870	0.0042	-0.0435	-0.0021	0.2966E-02	1275.00	800.00	0.000	0.000
2	0.1000	0.0049	0.0500	0.0024	0.2966E-02	1275.00	800.00	6.196	2.445
3	0.1150	0.0056	0.1575	0.0077	0.2966E-02	1275.00	800.00	13.321	3.233
4	0.1322	0.0064	0.2811	0.0137	0.2966E-02	1275.00	800.00	21.514	4.276
5	0.1521	0.0074	0.4233	0.0206	0.2966E-02	1275.00	800.00	30.937	5.655
6	0.1749	0.0085	0.5868	0.0285	0.2966E-02	1275.00	800.00	41.773	3.739
7	0.2011	0.0421	0.7748	0.0538	0.7000E-01	1625.00	800.00	110.123	4.945
8	0.2313	0.0484	0.9910	0.0990	0.7000E-01	1625.00	800.00	188.724	3.270
9	0.2660	0.0556	1.2397	0.1510	0.7000E-01	1625.00	800.00	279.116	4.324
10	0.3059	0.0640	1.5256	0.2108	0.7000E-01	1625.00	800.00	383.067	5.719
11	0.3518	0.0736	1.8545	0.2796	0.7000E-01	1625.00	800.00	502.610	3.782
12	0.4046	0.0846	2.2326	0.3587	0.7000E-01	1625.00	800.00	640.085	5.001
13	0.4652	0.0973	2.6675	0.4496	0.7000E-01	1625.00	800.00	798.180	3.307
14	0.5350	0.1119	3.1677	0.5542	0.7000E-01	1625.00	800.00	979.991	4.374
15	0.6153	0.1287	3.7428	0.6745	0.7000E-01	1625.00	800.00	1189.073	5.784
16	0.7076	0.1480	4.4043	0.8128	0.7000E-01	1625.00	800.00	1429.517	3.825
17	0.8137	0.1702	5.1649	0.9718	0.7000E-01	1625.00	800.00	1706.027	5.058
18	0.9358	0.1957	6.0396	1.1548	0.7000E-01	1625.00	800.00	2024.015	3.345
19	1.0761	0.2250	7.0456	1.3651	0.7000E-01	1625.00	800.00	2389.700	4.423
20	1.2375	0.2588	8.2024	1.6070	0.7000E-01	1625.00	800.00	2810.238	5.850
21	1.4232	0.2976	9.5328	1.8852	0.7000E-01	1625.00	800.00	3293.857	3.868
22	1.6367	0.3423	11.0627	2.2052	0.7000E-01	1625.00	800.00	3850.019	5.116

Most of T variation is above 0.02m, seen at KRC35@401

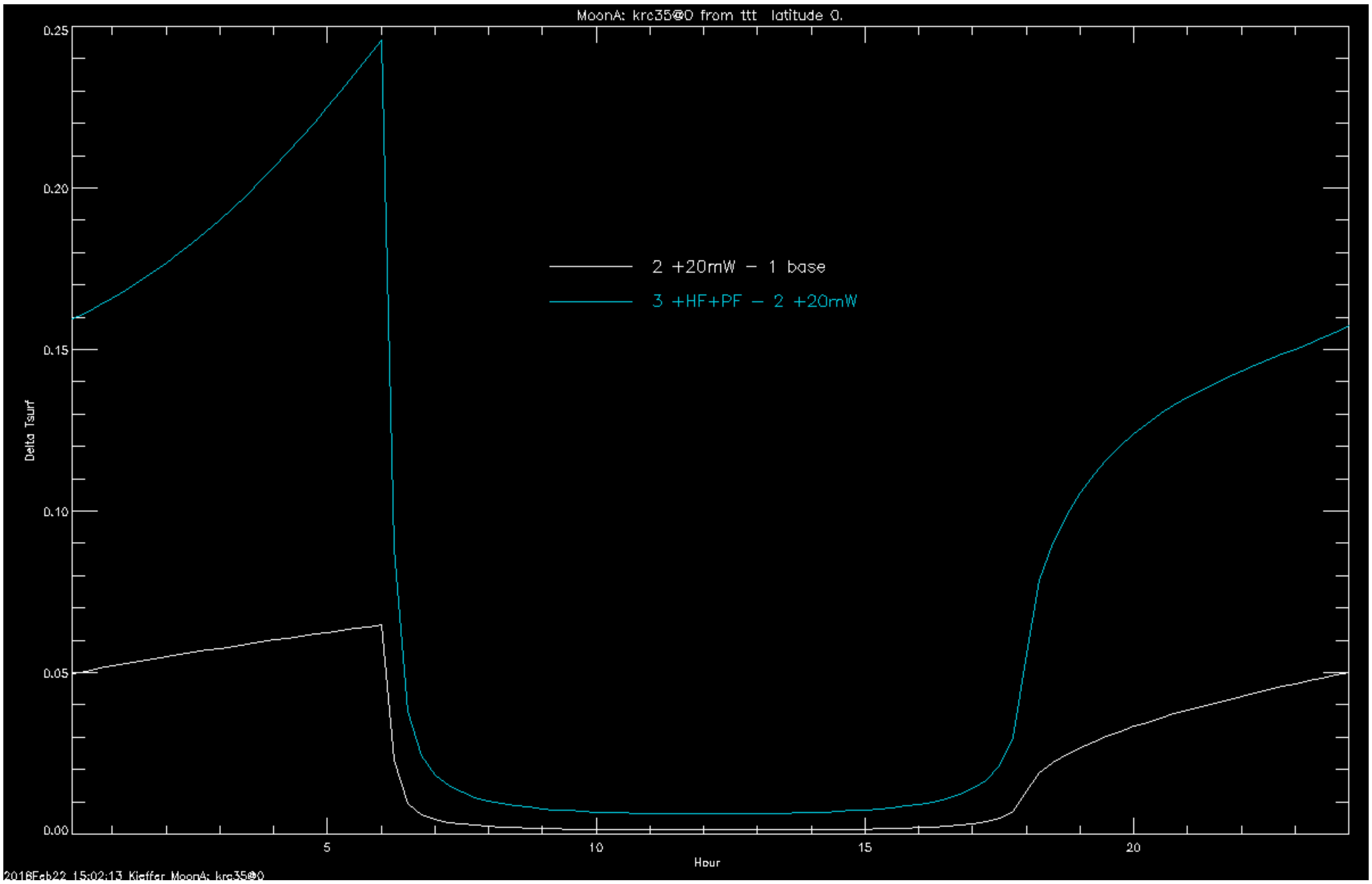

Figure 12: Change in diurnal surface temperature due to lunar heat flow (white curve) and radiation from Earth (blue curve), latitude 0. Although the radiation is largest near lunar midday, the effect on surface temperature is smallest then. The effect of Earth radiation is several times larger than lunar heat flow. Moon27a.png

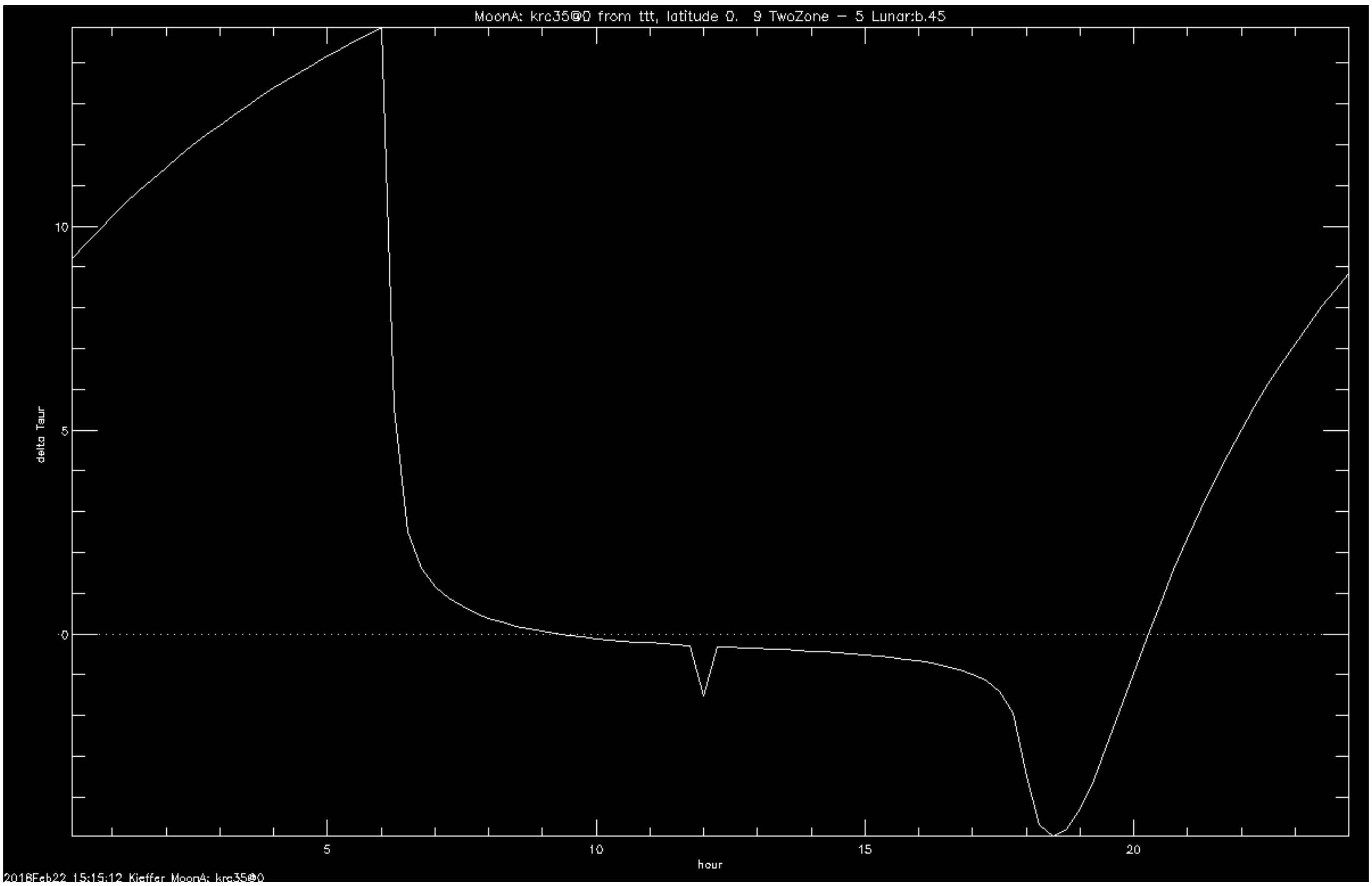

Figure 13: Difference of diurnal surface temperature from a homogenous material to two zones of temperature dependent materials. Moon27b.png

9 Summary of code changes

.

KRC:

In the case Loop, after TCARD and TPRINT, if any eclipse or planetary heat is active, will print: 'Eclipse or PlanHeat on',PARC(1),PARW(1)

Update PARC(12) with sol of EB in days

Calls TDAY(1

TSEAS: none

TLATS:

[un]set LPH (planetary heat) and LECL=Daily flags

Before the latitude loop, if Daily and first season, call ECLIPSE to get FINSOL

In lat loop, update PARC(11) with current latitude

In the time loop:

If LECL, multiply Sun by insolation factor; can affect TEQUIL

If LPH, calc PLANH(JJ) and PLANV(JJ).

After time Loop

If LPH, incorporate the average absorbed planetary heating into TEQUIL

after TDAY(2 call: If at NLAD latitude and last season. Write TOUT to binary file

TDAY(1:

[un]Set the LPH flag, [un]Set the LRARE flag

If LRARE,

call ECLIPSE to get the time-step range of eclipse, JBE

Set full eclipse range to start 1 time step earlier and end after 2nd duration

call TFINE(1 to do what can be done without temperatures

TDAY(2:

If the last day and LRARE and the last season, set JSW to start of eclipse

In the time loop, when reach JSW, then

if at start of eclipse call TFINE(2, before layer loop, then set JSW to end of eclipse followon J9 else, transfer TFINE results into layer temperatures, set JSW negative

After the layer loops: if LPH, add in the planetary heating at each time step

After last day, exit even if daily convergence tests fail (as they should)

TFINE(1: [called only for LRARE and only at start of eclipse on last day of last season]

call ECLIPSE to get both time range JBE and FINSOL

setthe range of ctime to treat. Set max possible eclispe for array size.

TFINE(2: Diffusion calculations.

Interpolates current T/depth profile.

Uses FINSOL and steps forward in fine-time until end of eclipse J8

Throughout the follow-on (J8 to J9) treat FINSOL as unity.

TFINE(3: Called by TLATS after latitude loop to write the *tfinexx.bin5* file.

Layer relations: 1-based

fine, first in set = I = (J-1)*KFL +1 where J is TDAY layer. KFL is layer factor

Time relations: 1-based. KFT=KFL^2

9.1 Coarse- and fine-time handoffs

ECLIPSE returns JBE; JBE(3) is the index of the last ctime interval before the start of eclipse. So, the handoff from TDAY to TFINE should occur at the start (before layer calculation) of the next ctime interval. JBE(4) is the index of ctime interval which contains the end of eclipse. JBE(1:2) contain the corresponding indices for the longest possible eclipse with the bodies and orbit specified, and are used to set storage array dimensions.

TFINE calls ECLIPSE to run in the "rare" mode, and TFINE covers ctime steps JBE(3)+1 through 2*JBE(4)-JBE(3) in fine-time.

On the last day of the last season:

to TFINE When ctime JJ reaches JBE(3)+1 but before the layer calculations, so the temperature profile is that at the end of JBE(3), call TFINE(2 .

from TFINE When JJ reaches 2*JBE(4)-JBE(3)+1, before the layer calculations, replace the T depth profile with that returned by TFINE.

9.2 Other

TCARD: reads and prints a 14 or 15 line, loads the values into PARC or PARW in HATCOM

Because the first real value is used as a test for activation, either effect can be turned off by a single negative value. e.g. 14 0. / turn off eclipses

Hour-dependant values computed in TLATS. Constant factors applied in TDAY.
In some cases, rather than logic tests for eclipse or Planetary loads, it is easier to always add them, but ensure they are zero when not invoked.

FINSOL in common used differently for daily and rare eclipses, which cannot be invoked at once. ECLIPSE calculates values only through the eclipse, so FINSOL must be replaced with 1.0 during the follow-on.

In TDAY, the insolation is evaluated at the instant of the middle of each time interval and the upper boundary condition evaluated after the diffusion ΔT is applied. Thus the assessment in ECLIPSE should also be at the middle of a TDAY interval. Strictly, the interpolation in TFINE should use the same instant, which can be done with no extra logic because eclipses cannot occur near the end s of the day (except at the poles)

As with TDAY, the upper boundary condition is applied after the layer loop for each timestep. In TDAY(2, TFINE(2 is called ???

A change 15 lien,

??? MORE
TFINE stores detailed output in CCC, but fine=time steps is 2nd dimension and this varys with latitude. So, need to compute longest possible eclipse for any latitude on EB and use that as dimension. For each latitude, save the eclipse-limit $b' = 0$ indices and put that in header.

Thus, ECLIPSE must compute maximum eclipse only for “rare” eclipse, but just as easy to do in either case.

For “solar” eclipse, shadow velocity is greater, and in the same direction, than surface velocity all solar-system cases,

10 Formulation

Starting with Equation wb=27 and some associated text of V34UG: <>>

$$\underbrace{W}_{POWER} = \underbrace{(1. - \overbrace{A_{h(i_2)}}^{ALBJ})}_{FAC3}\overbrace{S_M F_{\|}\cos i_2}^{ASOL} + \underbrace{(1 - \overbrace{A_s}^{SALB})}_{FAC3S} \underbrace{S_M \left(\overbrace{\Omega F_{\ominus}^{\downarrow}}^{DIFFUSE} + \overbrace{\alpha A_s (G_1 \cos i F_{\|} + \Omega F_{\ominus}^{\downarrow})}^{BOUNCE} \right)}_{SOLDIF}$$

$$+ \underbrace{\Omega\epsilon}_{FAC6} \underbrace{R_{\Downarrow}^0}_{ATMRAD} + \underbrace{k \frac{\partial T}{\partial z}_{(z=0)}}_{SHEATF} - \underbrace{\epsilon\sigma}_{FAC5} T^4 + \overbrace{\underbrace{(1-\Omega)\epsilon\sigma\epsilon_x}_{FAC5X} T_x^4}^{FARAD} \qquad \text{eq : wb} \tag{9}$$

where the overbrace items are computed in TLATS and transfered in COMMON. All terms up to and including ATMRAD make up the total absorbed radiation ABRAD. When frost is present, its albedo replaces A_h and A_s on a time-step basis except the A_s in SOLDIF (from TLATS) is on a season basis; however, the A_S term includes the far-ground fraction α which is small except for steep slopes.

Assumes that normal albedo is the same for the sloped and the flat surfaces.

The fraction of solar flux reflected ALBJ≡ A_h =ALB*AHF is composed of two factors, ALB≡ A_0 and AHF= $A_h(i)/A_h(0)$, a hemispherical reflectance function. Likewise, the spherical albedo is A_s = ALB*PUS where the second factor is P_s.

The floor of a "pit" does not see the flat terrain, but rather the same slope at all azimuths, and therefor different temperatures. The most practical assumption is that the average radiation temperature of the pit walls is the same as flat terrain. This will be an under-approximation. In a later version of KRC with more input parameters, a radiation scale factor could be included; if practical, code to include a constant factor, initally unity for v 3.4.

Because `FARAD` is not dependent upon the calculation of T, it can pre-computed for a given day. T_x is interpolated to the proper season in **TSEAS**; **TLATS** selects the proper latitude, multiplies by `FAC5X` for each of its stored hours, and interpolates to each time-step to form $\texttt{FARAD}_t$ transfered to `TDAY`. However, to then accomodate variable frost emission, need to multiply by ϵ_f/ϵ for the frost case (relatively rare). <<>

Version 3.5, add eclipse attenuation of solar insolation FINSOL= F_X and add visual and IR planetary fluxes, PLANV= P_V and PLANH= P_H. For daily eclipses, TLATS includes F_X into S_M, so that TDAY needs be no different. TLATS does nothing for rare eclipses and F_X in handled entirely within TFINE.

$$\underbrace{W}_{POWER} = \underbrace{(1.-\overbrace{A_{h(i_2)}}^{ALBJ})}_{FAC3}\overbrace{S_M F_\parallel \cos i_2}^{ASOL} + \underbrace{(1-\overbrace{A_s}^{SALB})}_{FAC3S}\left[\underbrace{S_M\left(\overbrace{\Omega F_\ominus^\downarrow}^{DIFFUSE} + \overbrace{\alpha A_s(G_1\cos i F_\parallel + \Omega F_\ominus^\downarrow)}^{BOUNCE}\right)}_{SOLDIF} + \mu_P P_V e^{-\tau_v/\mu_P}\right]$$

$$+\epsilon\mu_P P_H e^{-\tau_R/\mu_P} + \underbrace{\Omega\epsilon}_{FAC6}\underbrace{R^0_\Downarrow}_{ATMRAD} + \underbrace{k\frac{\partial T}{\partial z}_{(z=0)}}_{SHEATF} - \underbrace{\epsilon\sigma}_{FAC5}T^4 + \overbrace{\underbrace{(1-\Omega)\epsilon\sigma\epsilon_x}_{FAC5X}T_x^4}^{FARAD} \qquad \mathrm{eq:wbe} \qquad (10)$$

However, in version 3.5, the atmosphere effects on planetary fluxes are ignored, and the μ_P term is handled in TLATS.

ABRAD accumulates terms until SHEATF.

10.0.1 Synopsis of TLATS radiation calculations

```
TLATS
      LATM=PTOTAL.GT.1.0        ! atmosphere present flag
      LPH = PARW(1).GT.0.      ! doing planetary heat loads
      LECL= (ABS(PARC(1)-1.).LT. 0.2)       ! doing daily eclipses
      IF (LATM) allow twilight, else TWILFAC = 1. and LTW is False
      IF (LOPN3) setup TFAR8 and set LINT iff will need to interpolate in time
      SOLAU=SOLR=SOLCON/(DAU*DAU)! solar flux at this heliocentric range
      SALB=PUS*ALB              ! spherical albedo, for diffuse irradiance
        CALL ECLIPSE(PARC,PARI JBE, FINSOL) only if DailyEclipse and first season
in Lat. loop
 in time loop
  calc PUH= PhotFunc for horizontal surface using COSI
  calc AVEA=ALB*PUH and ensure 1-A cannot be negative
  If LATM do delta-Eddington, else
             TOPUP=COSI*AVEA         ! upward solar
             BOTDOWN=0.         ! no atm scattering
             ATMHEAT=0.         ! no atm absorbtion
             COLL=1.D0          ! no atm attenuation of beam
             DIRFLAT=COSI ! incident intensity on horizontal unit area
  if day or twilight
           DIFFUSE=SKYFAC*BOTDOWN ! diffuse flux onto surface
             G1=1.0D0
           BOUNCE=(1.D0-SKYFAC)*SALB*(G1*DIRFLAT+DIFFUSE)
  else
           DIFFUSE=0.
           BOUNCE=0.

  if  target is directly illuminated
   calc PUH=PhotFunc for (sloped) surface using COS2, HALB=ALB*PUH
           DIRECT=COS2*COLL
```

```
         IF (LECL) SOLR=SOLAU*FINSOL(JJ) ! eclipse factor     Daily only
         QI=DIRECT*SOLR         ! collimated solar onto slope surface

         ASOL(JJ)=QI            ! collimated insolation onto slope surface
         ALBJ(JJ)=MAX(MIN(HALB,1.D0),0.D0) ! current hemispheric albedo
         SOLDIF(JJ)=(DIFFUSE+BOUNCE)*SOLR ! all diffuse, = all but the direct.

         IF (LPH) THEN ! calc planetary heat loads and add to day sum
           PLANH(JJ) and PLANV(JJ)

         ADGR(JJ)=HUV=ATMHEAT*SOLR ! solar flux available for heating of atm. H_v
 end of time loop
        IF (LPH)  add in absorbed planetary heating
        IF (LATM)  set BETA and TEQUIL and other equilbrium temperatures
          else BETA=0. and set TEQUIL
         If first season TATMJ=77.7.  If no atm, no routine changes this
         CALL TDAY8 (2,IRL)      ! execute day loop
         Predict and store results
End of latitude loop
```

10.0.2 Synopsis of TDAY radiation calculations

```
TDAY(2
      FAC9=SIGSB*BETA           ! factor for downwelling hemispheric flux
      if no atm, ATMRAD=0.
Top of day loop
        IF (LDAY) THEN if LRARE and last season then JSW=JBE(1)-1
IN time loop:
       IF (JJ.EQ.JSW) and  JSW .LE. JBE(1)  CALL TFINE8  the reset JSW
                     else Transfer layer T's and set JSW=1
after layer loops: when no frost
            ABRAD=FAC3*ASOL(JJ)+FAC3S*SOLDIF(JJ) ! surface absorbed radiation
            IF (LATM) THEN
              ATMRAD=FAC9*TATMJ**4 ! hemispheric downwelling IR flux
              ABRAD=ABRAD+FAC6*ATMRAD ! add absorbed amount
            ENDIF
            IF (LPH) ABRAD=ABRAD+EMIS*PLANH(JJ)+FAC3S*PLANV(JJ)
            SHEATF= FAC7*(TTJ(2)-TSUR) ! upward heat flow to surface
            POWER = ABRAD + SHEATF - FAC5*TSUR*TS3 ! unbalanced flux
            IF (LOPN3) POWER=POWER+FARAD(JJ) ! fff only

          IF (LATM .AND. LSELF) THEN  !v-v-v-v-v  Adjust atmosphere temperature
            TATM4=TATMJ**4
C  ADGR is solar heating of atm
            HEATA=ADGR(JJ)+FAC9*(EMIS*TSUR4-2.*TATM4) ! net atm. heating flux
            TATMJ=TATMJ+HEATA*DTAFAC ! delta Atm Temp in 1 time step
          ENDIF                 !^-^-^-^-^

  IF (LATM) THEN  DOWNIR(IH,J4)=ATMRAD ! save downward IR flux  ELSE left as was!

            DOWNVIS(IH,J4)=ASOL(JJ)+SOLDIF(JJ) ! downward coll.+diffu. solar flux
```

11 Test results

11.1 Validation

Against 344. Minimal edit of 342/run/342v3t.inp to 344/run/344v3t.inp
difference negligable away from cap edges.

351: edit krc/Eur/351v3t.inp

11.2 New capabililties

12 Other version 3.5 changes

Replace EVMONO38 with EVMONO3D, which has the scaling factors firm-coded in the routine, eliminating 2 arguments. Latter routine is 9% faster

Change line: " 16 N 'ffff' " will toggle output of a binary file named ffffxx.bin5 for each case; xx will be the case number. This file will contain the surface temperature for every time step for the last season for the N'th latitude. A non-positive value of N turns this off.

Because all the KRCCOM arrays are full, add storage of N to HATCOM and use FMOON in FILCOM for the file name stem.

2018 Jan 21 18:12:12 routine that access:
ALBJ [to daycom]: tday tfine tun all already include daycom
SOLDIF [to daycom]: tday tfine tun
PLANH [to daycom]: tlats tday tfine
PLANV [to daycom]: tlats tday tfine
NOPE SALB [to krccom] tday tfine

References

[1] P. O. Hayne, J. L. Bandfield, M. A. Siegler, and 11. Others. Global regolith thermophysical properties of the Moon from the Diviner Lunar Radiometer Experiment. *preprint*, 777:77–77, 2018.

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

A Debug options new with v 3.5

TFINE always outputs *tfinexx.bin5*: ASOL, FINSOL and all layer temperatures at every fine time-step.
The file header contains N2,J7,J9,J4
array is [2+fine layer, fine-time] IDL krc35.pro reads as bbb

Optional files: Each may have more than one case

Table below: columns are:
1: Minimum IDB5 value to trigger output
2: fort.X file. P means it goes to print file. M means to Monitor
3: Routine that writes this. D=TDAY, F=TFINE. And which stage: 1 or 2

ID B5	out	St-age	Description	IDL code
1	P	F	IQ,JJ upon entry, print exit	
1	P	F1	Least stable layer and T-dep. layer set	
1	M	F1	QB.. key values	
1	P	D2	LZONE... T-dep layer ranges	
2	P	F2	Layer stability table	
2	42	F1	J,BLAF,SCONVF,QA for each fine layer	
3	P	F	Starting Tsurf, delbot	
4	43	F1	for N1 layers at start: TDAY: depth,T,splineY,c-thick,f-thick,f-depth	fff[layer,item]
	"	F1	for fine layers: depth, T, FA1, FA3	uuu[layer,item]
?	44	F2	JFI,FINSJ, TSUR,ABRAD,SHEATF,POWER,FAC7,KN each fine time near edge	ddd[ctime,item]
4	47	F2	T for fine layers and for coarse layers at end of eclipse, followed by :	vvv[item*case, layer]
4	47	D2	T for layers, just before being replace by eclipse results.	?
5	P	F	Index, center depth and initial temperature for each fine layer	
6	M	F	I,J, fine-layer factor for each layer	
7	44	F2	values for each fine time step near eclipse ends	
7	46	D2	JJ ,ATMRAD,TSUR,ABRAD,SHEATF,POWER,FAC7,KN each coarse time. Rare only.	aaa[time,item]

Notes: 1) Radiation fields do not show eclipse because they are normal for Rare eclipse
2) TSUR (and SHEATF) will show discontinuity at end of followon.

B Some values for Solar system satellites

Earth and Moon:
Eclipse card for Earth lunar eclipse might be
14 3 1. 6371.008 384.4e3 1737. 29.53 0.345 6000 12. 7 / Moon
Eclipse card for Earth solar eclipse might be
14 3 1. 1737.4 384.4e3 6315. 29.53 0.345 6000 12. 7 / Earth solar
but need to account for sol not the same as lunar synodic month
a test of the routine is that with bias=0, mid-eclipse would be about 6% short of total. Planetary FLux line: thermal amplitude and phase are just guesses 15 .05157 .005 20 0.011 0.011 0 12 / Earth flux onto Moon at lunar midday
Solid angle of Earth from Moon is 0.000216222 sterad .
https://nssdc.gsfc.nasa.gov/planetary/factsheet/earthfact.html
Earth: Bond Albedo 0.306 (highly variable)
Surface T =288, effectif T =252 blackbody=254

Wikipedia emissivity 0.96, but this is land only?
MENGLIN JIN, An Improved Land Surface Emissivity Parameter for Land Surface Models Using Global Remote Sensing Observations, Amer. Meteor. Soc 2006, p.2867

https://journals.ametsoc.org/doi/pdf/10.1175/2008BAMS2634.1
KEVIN E. TRENBERTH , JOHN T. FASULLO, AND JEFFREY KIEHL: EARTH'S GLOBAL ENERGY BUDGET Bull.Amer. Meteor. Soc, MArch 2009, p.311, Fig 1. global annual mean Earth's energy budget
Reflected solar 101.9 W/m2, outgoing Longwave=238.5 W/m2,

https://nssdc.gsfc.nasa.gov/planetary/factsheet/moonfact.html
Moon: Bond Albedo 0.11

https://arxiv.org/pdf/1711.00977.pdf
Global regolith thermophysical properties of the Moon from the Diviner Lunar Radiometer Experiment
Paul O. Hayne1 et al submitted to JGR, revised Sept 2017
Thermal conductivity varies from 7.410-4 W m-1 K-1 at the surface, to 3.410-3 W m-1 K-1 at depths of 1 m, given density values of 1100 kg m-3 at the surface, to 1800 kg m-3 at 1-m depth. On average, the scale height of these profiles is 7 cm, corresponding to a thermal inertia of 55 2 J m-2 K-1 s -1/2 at 273 K, relevant to the diurnally active near-surface layer, 4-7 cm.
These values lead to cond=3716, unreasonable. So, I estimate C at 800, compute k=0.107912

specific heat: polynomial in T [-3.6125,2.7431,2.3616e-3,-1.234e-5,8.9093e-8]
fit 0ver 120:320 to cubic in (T-220)/100 , get coef= [790.701,578.508,208.61,66.0619]
residual mean and stdev= -3.34023e-06 0.693955

Lunar heat flow, Langseth et al., 1976, quoted in:
  Lunar heat flow: Regional prospective of the Apollo landing sites,
    . A. Siegler, S. E. Smrekar JGP planets 2014 DOI: 10.1002/2013JE004453
Apollo 15 measured heat flux of 213mW m2 and the Apollo 17 values of 152
  but generally assumed these are above lunar average.

Mars: eq. radius = 3396.2 km
  Orbit SMA= 1.523679 AU
  Orbital Period 1.8808 yr or 686.971 day
Satellites =['Phobos','Deimos']
Satellite orbit radius = 9376., 23463.2 km
Satellite radius: 11.2667, 6.2 km
Mutual period 0.3189, 1.263 day
For Phobos solar eclipse, the surface radius of Mars is a significant term.

Jupiter: eq. radius =71492. km
  Orbit SMA= 5.2026 AU
  Orbital Period 11.8618 yr or 4332.59 day
Satellites =['Io','Europa','Ganymede','Callisto']
Satellite orbit radius =[.4218,.6711,1.0704, 1.8827]*1.e6
Satellite radius: =[3640.,3121.6,5268,2,4820.6] / 2.
Mutual period =[1.77,3.55,7.15,16.69] days
Angular radius of Jupiter from satellite: arctan(r/R)
  0.1703 0.1067 0.0668 0.0380

Europa heat flow: 30 to 130 mW/m2: J. Ruiz, 'The heat flow of Europa', Icarus v. 177, p438:446 (2005)

Calculations in **galsatab.pro**, using emission temperature of 125K and geometric albedo of 0.52:

```
Satt.        Io   Europa Ganymede Callisto
beta   0.16790  0.10613  0.06669  0.03920  angular radius of Jupiter from sat.
omega  0.08835  0.03535  0.01397  0.00483  Solid angle of jupiter, steradian
tflux   0.3893   0.1558   0.0615   0.0213  Mean IR flux  W/m^2
vflux   2.3213   0.9288   0.3670   0.1268  Maximum Vis flux  W/m^2
```

Thus, planHeat line for Europa might be:
  15 0.156 0. 0. 0.464 0.464 0. 12. / Jupiter heat load on Europa, nearside center

These can be compared to the solar irradiance at Jupiter of 50.53 W/m2

Saturn: Eq. radius. 60268 km
  Orbit SMA= 9.5549 AU
  Orbital Period 29.4571 yr or 10759.22 day
Satellites =['Enceledus','Titan','Iapetus']
Satellite orbit radius =[0.237950,1.22193,3.56082]*1.e6
Satellite radius: =[504.2,5149.,1468.6]/2. km
Mutual period =[1.370, 15.945 ,79.3215] days
  Titan has atm: Psurf=147 Pa N_2+ 1.4% CH_4
    Lakes and varied surface geology
  Iapetus has inclination 15.5°

Neptune: r_m=24622. SMA=30.33 AU
Triton, r=1353.4, sma=354759. incl.=157 (to nep)
  Psurf=1.4:1.9 Pa $N_2$2 , "geysers"

B.1 Test input files OBSOLETE

Chronologic; several run many times. Any run older than 2017 Apr 5 13:15 should be abandoned. Many .inp files deleted.

```
0=no eclipse, D=Daily, R=Rare H=PlanetaryHeating, n=nill
cirMars = circular orbit at Mars distance, zero obliquity

 3874 Dec  9 06:46 thin9.inp Mars  5 lats, 120 days, 9 cases: vary layers
 3448 Mar 20 16:50 V35a.inp Europa 5 lats, 20 days, 4 cases: 0,D,R,0H
 3536 Mar 30 12:49 eur6.inp Europa 1 lat, 10 days, 3 cases: 0, D and R
```

```
3168 Mar 30 14:21 phob.inp Mars, real phobos, 1 lat, 10 days, 3 cases: 0, D and R
3195 Mar 30 14:25 phon.inp Mars, no atm,  1 lat, 10 days, 3 cases: 0, D and R
3942 Mar 30 15:58 351v3t.inp  Mars 5-lats, 6 cases for standard V3 validation
3255 Mar 31 06:04 phoz.inp Mars,   1 lat, 10 days, 4 cases: all 0, vary PTOTAL
3339 Apr  2 16:22 phoc.inp cirMars 600 km Phobos 1 lat 4 cases: 0,D,R,Rn
4127 Apr  4 23:26 eurA.inp 1lat, 20 days
3916 Apr  5 15:38 eurB.inp Europa 1 lat,
3916 Apr  5 15:39 eurC.inp
```

Analysis of each run using IDL kv3 calling krc35

FORTRAN routines are tested individually using testrou.f, executable is testr

B.2 planning notes

Allow for an atmosphere.
  need to separate photometric function
  Daily: ?? add PlanIR to downir from atm?
    and add plan vis to downvis?

For rare eclipse, which calls TFINE, only case with atmosphere is Phobos, so need only handle atm for only one latitude! But may be simpler code to handle for all lats. Problem will be storage arrays; cannot use any in COMMMON.

But, could chose to not modify the atm temperature in tfine.

TFINE depth/time grid finer by K and K^2.

Interpolate boundary conditions: VIS attenuated by FINSOL ?

354 method computes TFINE before TDAY, so normal TATM is not available, except from prior day, which should be adequate.

If move TFINE after TDAY, then could compute TATM at each fine time step

but TAF(IH,J4) saved only on LDAY

Define bias at the center of the EB, then compute it for each latitude, calling ECLIPSE each time. Good for Earth:Moon lunar eclipse and slightly more accurate for Jovian Sat.

Could have TFINE results winnowed and replace TDAY in the output arrays!

For DAILY ecl, TLATS computes the bias and combo (DOWN + PlanFLux) fluxes current lat bias stored in PARC()

PlanFLux present for Daily as well as RARE ecl.

If Atm and DAILY, Tatm includes eclipse effects.

TFINE ignores any atmosphere, so RARE eclipse calculations ignore any atm. In the solar system, this is a significant approximation only for solar eclipses on Earth.

If ATM and RARE, Tatm would include eclipse effects on only the ecl day, could always ignore them. Decide based on code complexity.

Plan heat could include apparent declination of OB as a source.

B.3 Bugs in early versions

Tfine starts 255 higher than Tsurf 253. How can this be? For Rare sclipse, fort.43 contains Tsurf (fine) interpolating .t52 ttt Tsurf to the time of jj7, indicates Tfine start too high; as seen in plot krc35@25

CALL ORLINT8 (N1,XCEN,TTJ,N1F,XCEF,TTF

Asol computed with N2 resolution, TFINE does linear interpolation to fine-time of all time-based values from TLATS:
  ALBJ hemispheric albedo.
  ASOL Direct solar flux on sloped surface
  FARAD far-field radiance
  PLANH+PLANV combine IR and visual load from OB
  SOLDIF Solar diffuse (with bounce) insolation
If the first coarse time step into an eclipse is barely after eclipse starts, then the TFINE Tsurf may show a weaker slope until the end of the first coarse time-step.

B.4 Notes on the need to separate radiation fields

Want to allow planetary loads when have an atmosphere.

Must separate radiation fields:
  Solar incident top-of-atm. all and only these influenced by eclipse
    abs in atm,
    collimated at surface,
    diffuse at surface,
    [lost]
  Atm down-going IR
    Assume existing treatment included multiple reflections, messy to rederive
  Planetary visible top-of-atm: PLANV
    abs in atm,
    abs at surface
    [lost]
  Planetary thermal top-of-atm: PLANH
    abs in atm,
    abs at surface,
    [lost]
  Hemispherical albedo: ALBJ

C Integer to:from real conversion

Let a real value x run from 0 to V, e.g., 0 to 2π or 0. to 24.
Let the integral indices I representing this interval run from 1 to N; the 1-based system
  For notation convenience, define $R \equiv \frac{V}{N}$

```
x:  0=|++^++|++^++|++ ... ++|++^++|=V   Real representation
I:    |  1  |  2  |   ...   |  N  |     Integral representation, 1-based
M:    |  0  |  1  |   ...   | N-1 |     Integral representation, 0-based
```

Integer to real: $x = (I - \frac{1}{2})\frac{V}{N}$ or $x = (I - 0.5)R$
Real to integer: $I = \text{NINT}\ (x/R + .5)$
  BEWARE, the default real:integer conversion in many languages is to truncate magnitude.
    This results in a relationship discontinuity (no change in I) at $x = 0$.
      If y is always positive: NINT(y-.5) and INT(y) are identical.

or $I = x/R + 1$ if x is non-negative and the default real:interger conversion is to truncate magnitude.

FORTRAN intrinsics for real to integer (all tested in testrou.f @28)
  CEILING - Integer ceiling function
  FLOOR - Integer floor function
  INT - Convert to integer type identical results to I=x
    INT2 - Convert to 16-bit integer type
    INT8 - Convert to 64-bit integer type
    LONG - Convert to integer type
  NINT - Nearest whole number
  FLOAT - Convert integer to default real
Only CEILING, FLOOR,and NINT are consistent across 0.
The use of NINT and FLOAT maintains integrity.

C.0.1 version testing

```
 against 344.  minimal edit of 342/run/342v3t.inp to 344/run/344v3t.inp

351: edit krc/Eur/351v3t.inp

kv3.pro

File names
```

```
  0 VerA=new DIR    200 = ~/krc/Eur/out/
  1  " case file   202  = 351v3tb
  5 VerB=prior DIR 201  = /work2/KRC/344/run/out/
  6  " case file   202  = 344v3tb


@115 123 116 123
kv3 Enter selection: 99=help 0=stop 123=auto> 550
Num lat*seas*case with NDJ4 same/diff=        1197           3

@116 makes kons=233      56     561     562     563     564     565      61     622      -1      63


@56: t
@561: 0
.
% ARRSUB: some index error, see above comment
ARRSUB error        2
SOME ERROR CONDITION at kon=     561.  Any key to Go
@12  11=0 12=4 17=0 18=-1
@561
 help,qy
QY              DOUBLE    = Array[48, 5, 40, 6]

Tsurf caseRange=all LatRange=0:4  SeasonRange=all  hour   lat  seas  case
 quilt before any other display
                   Mean       StdDev      Minimum      Maximum
         1    -0.00101340    0.0169005    -0.800859    0.0731013  signed
N=   57600     0.00268893    0.0167159      0.00000     0.800859  absolute

kv3 Enter selection: 99=help 0=stop 123=auto>  562
351v3tb - 344v3tb:  Tsurf. caseRange=all LatRange=0:4  SeasonRange=all
         -60.         -30.           0.          30.          60.
% Compiled module: MEAN_STD2.
Mean= (each case)
    0.0453352      0.00000      0.00000      0.00000      0.00000
    0.0280654      0.00000      0.00000      0.00000      0.00000
   0.00726742      0.00000      0.00000      0.00000      0.00000
      0.00000      0.00000      0.00000      0.00000      0.00000
      0.00000      0.00000      0.00000      0.00000      0.00000
      0.00000      0.00000      0.00000      0.00000      0.00000
StDev=
    0.0616917      0.00000      0.00000      0.00000      0.00000
    0.0299598      0.00000      0.00000      0.00000      0.00000
    0.0100296      0.00000      0.00000      0.00000      0.00000
      0.00000      0.00000      0.00000      0.00000      0.00000
      0.00000      0.00000      0.00000      0.00000      0.00000
      0.00000      0.00000      0.00000      0.00000      0.00000

kv3 Enter selection: 99=help 0=stop 123=auto> 563
    Item       Mean     StdDev        Min        Max    MeanAbs     MaxAbs  0]=NDJ4
    NDJ4   -0.00167    0.07072   -2.00000    1.00000    0.00333    2.00000
    DTM4   -0.00000    0.00059   -0.00399    0.01548    0.00008    0.01548
    TTA4   -0.00036    0.00710   -0.10882    0.02495    0.00126    0.10882

QUILT3 displayed value range is      -0.10881889     0.024951097
sample is: latitude(5)  * 8 planes of case
line is: season(40)  * 1 groups of case.  Lines increase upward
SOuthern lats show the changes
  FROST4    0.05272    0.34532   -0.23976    3.60657    0.05312    3.60657
```

```
QUILT3 displayed value range is      -0.23975942       3.6065696
sample is: latitude(5)  * 8 planes of case
line is: season(40)  * 1 groups of case.  Lines increase upward
Any key to go
   AFRO4    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
  HEATMM   -0.00174    0.02303   -0.20097    0.11920    0.00585    0.20097
QUILT3 displayed value range is      -0.20096924      0.11919618
sample is: latitude(5)  * 8 planes of case
line is: season(40)  * 1 groups of case.  Lines increase upward

kv3 Enter selection: 99=help 0=stop 123=auto> 564
    Item       Mean     StdDev        Min        Max    MeanAbs     MaxAbs  0]=Lat
    Lat.    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
    elev    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000

kv3 Enter selection: 99=help 0=stop 123=auto> 565
    Item       Mean     StdDev        Min        Max    MeanAbs     MaxAbs  0]=DJU5
    DJU5    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
    SUBS    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
   PZREF    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
    TAUD    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
    SUMF    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
kv3 Enter selection: 99=help 0=stop 123=auto> 61
Maximum difference in Ls is:       0.0000000
kv3 Enter selection: 99=help 0=stop 123=auto> 62

RESULT, negligable differences away from frost edge.
```