Users Guide Ed4 LaRC Fu-Liou

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Fred G. Rose, SSAI (NASA_LaRC) Hampton,Va <fred.g.rose@nasa.gov>

ABSTRACT

This document serves as an imperfect first attempt to introduce a user to the inputs, output and basic subroutine calling sequences of Ed4 LaRC Fu-Liou broadband shortwave and longwave radiation transfer code. The intended audience of the code and this users guide is small, a handful of atmospheric science researchers and graduate students at most.

Introduction

The Ed4 LaRC Fu-Liou code computes broadband solar shortwave and thermal long wave profiles of down-welling and up-welling flux accounting for gas absorption by (H_2O, CO_2, O_3, O_2, CH_4, N_2O and CFC's) and absorption and scattering by clouds and aerosols. Longwave has options of a 4 stream or 2/4 stream solver, while shortwave has options for two-stream, four-stream or Gamma weighted two-stream (GWTSA) which treats the inhomogeniety of cloud optical depth (Kato et al. 2005) A delta-Eddington approximation is used to treat the forward scattering peak. Water cloud properties are based on Mie calculations (Hu & Stamnes 1993) and Ice cloud properties from Fu & Liou (1993, 1996) or a more recent set involving input of ice particle aspect ratio from Fu (2007). Aerosol properties are given for 25 types based on work by D'Amedia, OPAC(Hess) and Lacis & Tegin.

Options for four simultaneous computation modes are available:

1) Clear Sky: Aerosols, No Clouds
2) Total Sky: Aerosols and Clouds
3) Pristine: No Aerosol or Cloud
4) Total No Aerosol : Clouds but no Aerosol

A partly cloudy computation can be made. Cloud fraction as viewed from space is input for overlapped or non-overlapped cloud layers. Primary inputs for clouds are Fraction (viewed from space), Number of overlap layers, Cloud top and base pressure associated with each fraction and overlap layer, phase (1 =water, 2=Ice), particle size effective radius water cloud (Re), effective diameter ice cloud (De), and visible optical depth of cloud. For GWTSA mean optical depths both a logarithmetic and linear average are needed as a measure of optical depth inhomogeniety.

Aerosol inputs consist of aerosol type index (1-25), aerosol optical depth(s) and associated wavelength(s). Multiple constituents of differing aerosol type can be used in a single computation. Additionally the aerosol vertical profile for each aerosol constituent can be specified though a subroutine is provided to create these profiles using a scale height assumption.

Surface shortwave spectral albedo (18 bands) and longwave spectral emissivity (12 bands) are required. Surface spectral albedo can vary between clear and cloudy conditions.

MODEL INPUT OVERVIEW

Model input and output are contained in FORTRAN structures as defined below. The original method of inserting clouds in the model involved defining a cloud liquid or ice water content profile along with particle size profile. Now the LaRC Fu & Liou model used in CERES Surface and Atmospheric Budget products is modified to been use satellite retrieved cloud optical depth and variable cloud top and base pressures as the primary inputs instead of IWC/LWC profiles.

fi% : Structure containing INPUTS to Fu-Liou code

There is an optional set of inputs and subroutines that creates the model levels and inserts layers according to cloud tops and bases. The high level inputs are in the structure "fi%vi" and "fi%vd" while the lower level inputs do not have these "vi" or 'vd" substructure tags. The included simple.f90 uses this high level method to input a standard atmosphere profile containing 32 layers into fi%vi(pp,pt,ph,po) and defines cloud top and base levels using "FI%VD%cldpre". An alternate vertical level structure is created with inputs in the 'gflq%" structure in the subroutine call:

call generate_level_scheme

Once the alternate vertical grid structure with unique cloud tops and bases is defined, the following two subroutines are called to set up and interpolate to the actual model inputs of pressure, temperature, humidity , ozone profiles placed in fi%(pp,pt,ph, po).

call prepare_model_profile_fu !! CALL After all FI%VD and FI%VI structures are defined.

call vla_interface_fu ! uses FI%VO !! Assign Model ATM Profile and CLD Levels

Some diagnostic printout of the intermediate steps can be seen using calls to:

call print_vla_in

call print_vla_out

PRIMARY SUBROUTINES CONTIANED IN FU_LIOU LIBRARY:

GENERATE_LEVEL_SCHEME:

The 'generate_level_scheme' subroutine (in glfq.f90) creates a set of model input pressure levels for a couple of different vertical resolutions. Its inputs are passed through the gflq% structure. This code can be thought of a guide as what and how to create the model pressure level structure in fi%vd.

gflq%hsfc : height of the surface in meters.

gflq%mode: character flag for vertical level creation , these are limited see gflq.f90.

gflq%internal_levels(1:gflq%nld): set of fixed pressure levels to be certain to include in vertical level creation. Array works in conjunction with 'Pack_Sky" (see below) to extract output flux profile at these levels.

gflq%nld: # of levels in gflq%internal_levels

PREPARE_MODEL_PROFILE_FU:

Subroutine 'prepare_model_profile_fu' is called after all FI%VD and FI%VI structures are defined. This subroutine dose several things including sorting input profile, merges fixed, floating and cloud levels, removes levels that are too close (<1hPa), finds indexes for reporting a subset of fixed pressure levels. And interpolates (T, Q, O3) from input structure fi%vi. Outputs are contained in the model structure fi%vo.

VLA_INTERFACE_FU:

Subroutine 'vla_interface_fu' uses FI%VO output from 'prepare_model_profile_fu' to assign the 'low level' model vertical pressure level structure fu%(pp,pt,ph,po) atmosphere and fi%fc%(icld_top, icld_bot) cloud level layer indexes.

RAD_MULTI_FU:

Subroutine 'rad_multi_fu' is the primary call to the broadband radiative transfer code. It computes (Clear, Cld(1:mccx) , Pristine , Cld_NoAer(1:mccx) cases and combines these to report the possible "Total_Sky" fluxes which may be for partly cloud conditions if input as such. The longwave and shortwave solvers are called for several correlated-k instances per 18 Shortwave and 12to14 Longwave bands. See fi%lscm(1:4) for 'turning-on/off' (Clear, Total, Pristine, Total_NoAer) cases.

PACK_SKY:

The 'pack_sky' subroutine function is optional. It extracts output fluxes for a set of pressure levels that are a subset of the complete model level calculations.

fi%vo%ireport(1:)

gflq%nld =4
gflq%internal_levels(1:4) = (/70.,200.,500.,850./)

PRINT/DEBUGGING SUBROUTINES:

call print_vla_in: prints out selected arrays from fi%vi and fi%vd structures. Should only be called after 'generate_level_scheme' has been called. Mainly for debugging.

call print_vla_out: prints out selected arrays from fi%vi and fi%vd structures. Should only be called after 'generate_level_scheme, prepare_model_profile_fu and vla_interface_fu' have been called. Mainly for debugging.

call 'print_fu_in': a verbose print of most all of the low level model inputs and option flags. Best to call just before 'rad_multi_fu'.

call 'print_fu_out': a verbose print of most all of the low level model outputs . Best to call just after 'rad_multi_fu'.

Call 'print_pack_sky': print out of flux profiles for selected subset of vertical pressure levels of shortwave, longwave and window fluxes for all four computation modes (Clear, Total, Pristine, Total_NoAer)

MODEL INPUT:

See /lib/src/fuinput.f90 for structure definitions of "fi%"

call set_default_options_fu: sets many of the obscure fi% input variables to 'reasonable' values.

fi%nv: Number of model LAYERS

fi%nirold: suggested to set .false. Turns on older obsolete features.

fi%curvedearth: turns on a correction to cosSZA to limit path length at low sun.

fi%umco2: CO2 concentration (ppmv) affects LW only , SW amount fixed at year 2000 concentration.

fi%umch4: CH4 concentration (ppmv) affects LW only , SW amount fixed at year 2000 concentration.

fi%umn2o: N2O concentration (ppmv) affects LW only , SW amount fixed at year 2000 concentration.

fi%cfc_conc(1:3): CFCs concentration (ppv) affects LW only , no SW contribution.

fi%txt: Ice cloud property source texture flag (1=smooth) (2==rough), (0=fu1996). If fi%txt equals 1 or 2 one needs to input an ice cloud aspect ratio in array "fi%fc%asp" in addition to other cloud inputs.

fi%lband6a: If .true. crudely treats ~11Wm^{-2} solar > 4µm, .false. then only to 4µm.

fi%irobckd: index for parameterized LW continuum, 5 = CKD2.4.

fi%nhb=2: use two 'hidden' bands for thermal LW 2200-2500-2850cm-1

fi%wp_hgt_flag: flag to manage ice water contant vertically through a cloud.

0 = Constant IWC with cloud height

1 = Increase linearly with height

2 = Decrease linearly with height

3 = Decrease with height parameterized Calipso profile (SH.HAM)

fi%ss: Solar Insolation (Wm^{-2}), around 1361, but one needs to provide this for the day of year modified by 1/earth-sun distance^2

fi%u0: Cosine of solar zenith angle (0-1.0)

fi%ur: Cosine of satellite view zenith angle for optional longwave radiance output fi%lscm(1:4) = .true. Turn On (Clear, Cloudy,Pristine, CloudNoAerosol) modes . You can set some to false to turn-off unneeded computations.

Example: fi%lscm(1:4) = (/ .true., .false., .false., .false. /) gives clear sky only.

fi%HYBRID_SW_SOLVER:

When TRUE: 4 Stream clear sky, 2 Stream Homogeneous Cloud , GWTSA Inhomogeneous Cloud

When FALSE checks isksolve, fourssl

fi%isksolve: Solver Method (0=fu 1=gwtsa) when fi%HYBRID_SW_SOLVER =.false.

if (.not. fi%HYBRID_SW_SOLVER .and. fi%isksolve == 0)then

fi%fourssl : (.true. Fu 4 stream) (.false. Fu 2 stream)

fi%foursir : (.true. 4stream LW solver) (.false. 2/4stream LW solver)

fi%instrument: Satellite Window Instrument for emulation of CERES window channel radiance.

[0=TRMM, 1=FM1,2=FM2, 3=FM3 4=FM4]

ATMOSPHERE STRUCTURE INPUTS:

These are the low-level model vertical level inputs

fi%nv: number of input model LAYERS.

fi%pp(1: fi%nv+1): Pressure LEVELS in (hPa) monotonically increasing TOA to SFC.

fi%pt(1: fi%nv+1): Temperature (K) at each pressure LEVEL.

fi%ph(1: fi%nv+1): H2O Mixing Ratio (g/g) at each pressure LEVEL.

fi%po(1: fi%nv+1): O3 Mixing Ratio (g/g) at each pressure LEVEL.

fi%pts: Skin Temperature (K) at Surface.

CLOUD INPUTS:

Example One: The following inputs are for an overcast cloud condition containing two layers. The top layer is an Ice cloud with a effective diameter particle size of 60μm of optical depth 1.0 from 200 to 400hpa. A second layer, which is overlapped by the upper layer, has a water cloud of effective radius 10 μm with an optical depth 10.0 occurring between 704 and 725 hPa. Within each cloud layer between each cloud top and base the ice and water content is constant with height. The total optical depth is 11.0. The gamma weighted two-stream solver is called for shortwave computations.

fi%fc%dpi%ldpi = .false. ! Setting this avoids direct insertion of level-by-level IWC/LWC. For the reset of the document will assume this is set FALSE.

fi%fc: Structure containing Cloud Inputs for 1-mccx Max number of Cloud conditions as viewed from space, mccx currently set to 4 in fuinput.f90.

fi%fc(1)%cldfrac = 1.0 ! Cloud fraction for cloud condition "1" set to 1.0 ie. Overcast

fi%fc(1)%novl = 2 ! Cloud condition "1" has 2 overlapped layers with associated properties.

FI%VD%cldpres(1:2, 1,1) = (/200,400/) ! Upper overlap layer has top at 200hpa base at 400hpa.

FI%VD%cldpres(1:2, 1,2) = (/704,725/) ! Lower overlap layer has top at 704hpa base at 725hpa

fi%fc(1)%rphase(1) = 2.0 ! Upper layer Cloud Phase is 2=Ice.

fi%fc(1)%de(1) = 60. ! Upper layer Ice particle size De = 60μm.

fi%fc(1)%rphase(2) = 1.0 ! Lower layer Cloud Phase is 1=Water

fi%fc(1)%re(2) = 10. ! Lower layer particle size Re =10 μm.

fi%fc(1)%tau_vis(1) = 1.0 ! Cloud Visible Optical Depth (from log mean) Upper Layer.

fi%fc(1)%sc(1)%mn_lin_tau = 1.15 ! Cloud Visible Optical Depth (linear mean) Upper Layer.

fi%fc(1)%tau_vis(2) = 10.0 ! Cloud Visible Optical Depth (from log mean) Lower Layer.

fi%fc(1)%sc(2)%mn_lin_tau = 11.5 ! Cloud Visible Optical Depth (linear mean) Lower Layer.

fi%wp_hgt_flag = 0 ! Constant LWC/IWC with height.

fi%HYBRID_SW_SOLVER = .false.

fi%isksolve = 1 ! GWTSA

Example Two: The following inputs are for a partly cloudy cloud condition containing two cloud conditions in the 'grid-box'. The first condition occupies 25percent of the 'grid-box', as seen from space, which is Ice cloud with an effective diameter particle size of 50 μm of optical depth 2.0 from 300 to 500 hPa. The second cloud condition occupies 50% of the 'grid-box' is a water cloud of effective radius 12µm with an optical depth 2.0 between 800 and 900 hPa. Within each cloud layer the ice and water content is constant with height. The total cloud fraction is 0.75. The cloud fraction weighted optical depth for the partly cloud grid box is 4.0. The original fu two-stream solver is called for shortwave computations.

fi%fc: Structure containing Cloud Inputs for 1-mccx Max number of Cloud conditions as viewed from space, mccx currently set to 4 in fuinput.f90.

fi%fc(1)%cldfrac = 0.25 ! Cloud fraction for cloud condition "1" set to 0.25 .

fi%fc(2)%cldfrac = 0.50 ! Cloud fraction for cloud condition "2" set to 0.50 .

fi%fc(1)%novl = 1 ! Cloud condition "1" has only one layer.

fi%fc(2)%novl = 1 ! Cloud condition "2" has only one layer.

FI%VD%cldpres(1:2, 1,1) = (/300,500/) ! First cloud condition has top at 300hpa base at 500hpa.

FI%VD%cldpres(1:2, 2,1) = (/800,900/)! Second cloud condition has top at 800hpa base at 900hpa.

fi%fc(1)%rphase(1) = 2.0 ! First cloud condition Phase is 2=Ice.

fi%fc(1)%de(1) = 50. ! Upper layer Ice particle size De =50 µm.

fi%fc(2)%rphase(1) = 1.0 ! Second cloud condition Phase is 1=Water.

fi%fc(2)%re(1) = 12. ! Second cloud condition particle size Re =12 µm.

fi%fc(1)%tau_vis(1) = 2.0 ! Cloud Visible Optical Depth (from log mean) first cloud condition.

fi%fc(1)%sc(1)%mn_lin_tau = 2.0 ! Cloud Visible Optical Depth (from linear mean).

fi%fc(2)%tau_vis(1) = 5.0 ! Cloud Visible Optical Depth (from log mean) second cloud condition.

fi%fc(2)%sc(1)%mn_lin_tau = 5.0 ! Cloud Visible Optical Depth (from linear mean) second cloud condition..

fi%wp_hgt_flag = 0 ! Constant LWC/IWC with height

fi%HYBRID_SW_SOLVER = .false.

fi%isksolve = 0 ! Original fu solver

fi%fourssl = .false. ! Use two-stream shortwave Fu solver.

SURFACE INPUTS:

The input structure for spectral surface albedo allows unique albedo for aerosol Vs. no Aerosol cases and unique albedo for each Clear/Cloud Conditions The dimensions correspond to shortwave band (1:18); Aerosol with (1), without(2) , Cloud Condition (0 clear) (1 cldcnd1) (2 Cldcnd 2) … up to cldcnd(mccx). See band structure section for corresponding wavelength ranges for 18 SW bands. Surface albedo is assumed to be Lambertian.

Example: Surface Albedo is set to zero in all cases.

fi%sfcalb(1:18,1,0) = 0.0 ! Clear sky -Spectral Surface Albedo SW

fi%sfcalb(1:18,2,0) = 0.0 ! Pristine sky -Spectral Surface Albedo SW

fi%sfcalb(1:18,1,1:) = 0.0 ! CLOUDY with AOT sky-Spectral Surface Albedo SW

fi%sfcalb(1:18,2,1:) = 0.0 ! CLOUDY without AOT sky-Spectral Surface Albedo SW

One spectral emissivity is input for all cloud and aerosol conditions. See band structure section for corresponding wavelength ranges for 12 Lw bands.

fi%ee(1:12) = 0.99 ! Spectral Surface Emissivity LW

fi%pts ! Skin Temperature(K) at Surface

AEROSOL INPUTS:

In the following example we input aerosol for two constituents. The first constituent has a "type index" of 1 for 'maritime' with an optical depth of 0.195 at wavelength 0.641 µm. The second constituent has a "type index" of 11 for 'soot' with an optical depth of 0.005 at wavelength 0.641 µm. The subroutine "aer_scale_hgt" is called to fill the vertical profiles of each constituent with profiles consistent with scale height of 3km. Note: "aer_scale_hgt" must be called after fi%pp(1:fi%nv) atmospheric pressure profile is created. See appendix for aerosol constituent indexes.

fi%nac = 2 ! Two aerosol constituents are used.

fi%itps(1) = 1 ! D'Almedia Maritime See types (1-18)

fi%itps(2) = 11 ! Soot See types (1-18)

fi%n_atau = 1 ! 1 Wavelength input for aerosol optical depth

fi%a_wli(1) = 0.641 ! AOT wavelength (µm) of a_taus

fi%a_taus(1,1) = 0.195 ! AOT@0.641 for constituent 1 (maritime) fi%a_taus(1,2) = 0.005 ! AOT@0.641 for constituent 2 (soot)

call aer_scale_hgt(fi%nv,fi%pp,3.0,fi%aprofs(1:fi%nv,1))

call aer_scale_hgt(fi%nv,fi%pp,3.0,fi%aprofs(1:fi%nv,2))

MODEL OUTPUTS:

See file /lib/src/fuoutput.f90 for structure definitions of (fo% ftoa% fsfc% fos% foscc% fo%uv")

Ftoa% structure is an array of four giving (1=Clear-Sky (aerosol), 2=Total-Sky (cloud and aerosol), 3=Pristine-Sky (No Aerosol), 4=Total_sky(Cloud ,No Aerosol)] it contains SW,LW , Window fluxes and LW and Window radiances at the TOP of the input atmosphere.

Ftoa(1:4)%swdn: shortwave broadband downward flux at TOA (Wm^{-2})

Ftoa(1:4)%swup: shortwave broadband upward flux at TOA (Wm^{-2})

Ftoa(1:4)%swalb: shortwave broadband albedo at TOA

Ftoa(1:4)%olr: longwave broadband upward flux at TOA (Wm^{-2})

Ftoa(1:4)%wnolr: longwave window upward flux at TOA (Wm^{-2})

Ftoa(1:4)%totrad: longwave broadband upward radiance at TOA ($Wm^{-2}\ sr^{-1}$)

Ftoa(1:4)%winrad: longwave window upward radiance at TOA ($Wm^{-2}\ sr^{-1}$)

Ftoa(1:4)%trwn_flt_r : longwave window upward radiance at TOA ($Wm^{-2}\ sr^{-1}$) modeled for FILTERED CERES Instrument response function

Ftoa(1:4)%trwn_unf_r : longwave window upward radiance at TOA ($Wm^{-2}\ sr^{-1}$) modeled over UNFILTERED CERES (over 2.7um width)

Ftoa(1:4)%trwn_unf_f : longwave window upward flux at TOA (Wm^{-2}) modeled over UNFILTERED CERES instrument (over 2.7um width)

Fsfc% structure is an array of four, giving (1=Clear-Sky (aerosol), 2=Total-Sky (cloud and aerosol), 3=Pristine-Sky (No Aerosol), 4=Total-sky (Cloud, No Aerosol)] it contains SW,LW , Window at the SURFACE of the input atmosphere.

Fsfc(1:4)%swdn: shortwave broadband downward flux at surface (Wm^{-2})

Fsfc(1:4)%swup: shortwave broadband upward flux at surface (Wm^{-2})

Fsfc(1:4)%swalb: shortwave broadband albedo at surface.

Ftoa(1:4)%swdir : shortwave broadband direct beam flux at surface (Wm^{-2})

Ftoa(1:4)%swdif : shortwave broadband diffuse beam flux at surface (Wm^{-2})

Fsfc(1:4)%swpar: shortwave photosynthetic active flux down at surface (Wm^{-2})

Fsfc(1:4)%lwdn: longwave broadband downward flux at surface (Wm^{-2})

Fsfc(1:4)%lwup: longwave broadband upward flux at surface (Wm^{-2})

Fsfc(1:4)%wndn: longwave window downward flux at surface (Wm^{-2})

Fsfc(1:4)%wnup: longwave window upward flux at surface (Wm^{-2})

Fo% structure is an array of four, giving (1=Clear-Sky (aerosol), 2=Total-Sky (cloud and aerosol), 3=Pristine-Sky (No Aerosol), 4=Total-sky (Cloud, No Aerosol)] it contains SW,LW , Window Flux and LW radiance PROFILES from toa to surface at fi%pp pressure levels. Heating rates refer to LAYER bounded by upper and lower level

Fo%(1:4)%fds(1:fi%nv+1): shortwave downward broadband flux profile (Wm^{-2})

Fo%(1:4)%fus(1:fi%nv+1): shortwave upward broadband flux profile (Wm^{-2})

Fo%(1:4)%fdsdr(1:fi%nv+1): shortwave downward broadband direct beam flux profile (Wm^{-2})

Fo%(1:4)%fdsdf(1:fi%nv+1): shortwave downward broadband diffuse beam flux profile (Wm^{-2})

Fo%(1:4)%dts(1:fi%nv): shortwave broadband heating rate profile (K day^{-1})

Fo%(1:4)%fdir(1:fi%nv+1): longwave downward broadband flux profile (Wm^{-2})

Fo%(1:4)%fuir(1:fi%nv+1) : longwave upward broadband flux profile (Wm^{-2})

Fo%(1:4)%dtir(1:fi%nv): longwave broadband heating rate profile (K day^{-1})

Fo%(1:4)%fdwn(1:fi%nv+1): longwave downward window flux profile (Wm^{-2})

Fo%(1:4)%fuwn(1:fi%nv+1): longwave upward window flux profile (Wm^{-2})

Fos% structure is an array of dimension four (1=Clear-Sky (aerosol), 2=Total-Sky (cloud and aerosol), 3=Pristine-Sky (No Aerosol), 4=Total-sky (Cloud, No Aerosol)] it contains SW, LW, Window Flux PROFILES from TOA to surface at fi%pp pressure levels. For 18 shortwave bands and 12 longwave bands numbered (10:23). Arrays for surface and TOA spectral albedo and surface direct and diffuse beam spectral shortwave flux and spectral surface shortwave flux corrected for ice cloud conditions consistent with delta-eddington approximation.

Fos%(1:4)%rswfd(1:fi%nv+1, 1:18): Spectral shortwave downward broadband flux profile (Wm^{-2})

Fos%(1:4)%rswfu(1:fi%nv+1, 1:18): Spectral shortwave upward broadband flux profile (Wm^{-2})

Fos%(1:4)%rswdir(1:fi%nv+1, 1:18): Spectral shortwave downward direct beam broadband flux profile (Wm^{-2})

Fos%(1:4)%rswdif(1:fi%nv+1, 1:18): Spectral shortwave downward diffuse beam broadband flux profile (Wm^{-2})

Fos%(1:4)%rlwfd(1:fi%nv+1, 10:23): Spectral longwave downward broadband flux profile (Wm^{-2})

Fos%(1:4)%rlwfu(1:fi%nv+1, 10:23): Spectral longwave upward broadband flux profile (Wm^{-2})

Fos%(1:4)%sbf(1:fi%nv+1, 10:23): Spectral longwave emitted broadband flux at layer profile 'source function' (Wm^{-2})

Fos%(1:4)%sbs(10:23): Spectral longwave emitted broadband flux at surface 'source function' (Wm^{-2})

Fos%(1:4)%specalbtoa(1:18): Spectral shortwave top of atmosphere albedo (0-1)

Fos%(1:4)%specalbsfc(1:18): Spectral shortwave surface albedo (0-1)

Fos%(1:4)%dirsfc(1:fi%nv+1, 1:18): Spectral shortwave downward 'corrected' direct beam broadband flux at surface (Wm^{-2})

Fos%(1:4)%difsfc(1:fi%nv+1, 1:18): Spectral shortwave downward 'corrected' diffuse beam broadband flux at surface (Wm^{-2})

Fouv% structure is an array of four, giving (1=Clear-Sky (aerosol), 2=Total-Sky (cloud and aerosol), 3=Pristine-Sky (No Aerosol), 4=Total-sky (Cloud, No Aerosol)] it contains UVA, UVB, UV index, PAR at TOA and surface. PAR Purves, PAR chlorophyll-A action spectra fluxes & direct/diffuse ratios at surface.

Fouv(1:4)%toa_uvb: TOA downward flux over UVB portion of shortwave (Wm^{-2})

Fouv(1:4)%toa_uva: TOA downward flux over UVA portion of shortwave (Wm^{-2})

Fouv(1:4)%toa_par: TOA downward flux over PAR portion of shortwave (Wm^{-2})

Fouv(1:4)%uvb: Surface downward flux over UVB portion of shortwave (Wm^{-2})

Fouv(1:4)%uva: Surface downward flux over UVA portion of shortwave (Wm^{-2})

Fouv(1:4)%par: Surface downward flux over PAR portion of shortwave (Wm^{-2})

Fouv(1:4)%uvb_rdifdif: Direct/Diffuse ratio of surface downward flux over UVB portion of shortwave

Fouv(1:4)%uva_rdifdif: Direct/Diffuse ratio of surface downward flux over UVA portion of shortwave

Fouv(1:4)%par_rdifdif: Direct/Diffuse ratio of surface downward flux over PAR portion of shortwave

Fouv(1:4)%uvb ery: Index ofUVB portion of shortwave at surface “UV_INDEX”

Fouv(1:4)%par_purv: Surface downward flux over PAR Purves action spectra portion of shortwave (Wm^{-2})

Fouv(1:4)%par_purv_rdifdif: Direct/Diffuse ratio of surface downward flux over PAR Purves action spectra portion of shortwave

Fouv(1:4)%par_chla: Surface downward flux over chlorophyll-A action spectra portion of shortwave (Wm^{-2})

Fouv(1:4)%par_chla_rdifdif: Direct/Diffuse ratio of surface downward flux over chlorophyll-A action spectra portion of shortwave

Confessional Epilog: It is my sincere hope that this document helps a new user of the code to understand and run the example code contained in the distribution as well as to understand its inputs and outputs and subsequently adapt and modify inputs and outputs to suit their own environment. The Fu-Liou code has been modified several times since obtaining the original version the mid 1990's from Qiang Fu, altering cloud and aerosol properties, adding additional bands in three stages covering UV/VIS, Thermal LW > 2200cm-1, SW Near-IR, modifying the longwave continuum in the window and Far-IR. Adding the Gamma-Weighted two-stream solver. The code in its forms has been used in the Clouds and Earths Radiant Energy System (CERES) Surface and Atmosphere Radiation Budget Project (SARB) for over a decade. There are still occasional problems; under some conditions the LW solver, Nan's are generated. In the shortwave, conditions of high surface albedo and low clouds may cause a numerical instability in bands with little gas absorption ~400nm. The optional treatment of the solar > 4micron is very crude.

Selected References: Available from CERES CAVE web site

http://dev-www-cave.larc.nasa.gov/pdfs/Kato.JAOTECH04.pdf

- Kato, S., F.G., Rose, and T.P., Charlock, 2005: *Computation of Domain-Averaged Irradiance Using Satellite-Derived Cloud Properties*, J. of Atmos. Ocean. Tech., **22b**, pp 146-164.

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- F. G. Rose, T. P. Charlock, Q. Fu, S. Kato, D. A. Rutan, and Z. Jin, 2006: *CERES Proto-Edition 3 Radiative Transfer: Model Tests and Radiative Closure Over Surface Validation Sites*, Proceedings 12th Conf. on Atmos. Radiation, Madison, WI

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- Qiang Fu and K. N. Liou, 1993: *Parameterization of the Radiative Properties of Cirrus Clouds*, J. Atmos. Sci., **50**, pp 2008-2025.

APPENDIX:

Here are the band boundaries and number of absorption "K"s per band of the shortwave and longwave. Only gases H2O and CO2 are able to vary for shortwave bands, O2, CO2, CH4 concentrations are fixed.

SW	Bands			Wavelength (Micron)		Wavenumber (cm-1)		
	Band#	Alternate Band#	#K's	Begin	End	Beg	End	Gases
	1	1	1	0.1754	0.2247	57000	44500	O3
	2	1	1	0.2247	0.2439	44500	41000	O3
	3	1	1	0.2439	0.2857	41000	35000	O3
	4	1	1	0.2857	0.2985	35000	33500	O3
	5	1	1	0.2985	0.3225	33500	31008	O3
	6	1	1	0.3225	0.3575	31008	27972	O3
	7	1	1	0.3575	0.4375	27972	22857	O3
	8	1	1	0.4375	0.4975	22857	20101	O3&H2O
	9	1	1	0.4975	0.595	20101	16807	O3&H2O
	10	1	1	0.595	0.6896	16807	14500	O3&H2O
	11	2	8	0.69	0.794	14500	12600	H2O&O2&O3
	12	3	6	0.794	0.889	12600	11250	H2O
	13	4	8	0.889	1.042	11250	9600	H2O
	14	5	7	1.042	1.41	9600	7090	H2O
	15	6	8	1.41	1.9048	7090	5250	H2O&CO2
	16	7	7	1.9048	2.5	5250	4000	H2O&CO2&CH4
	17	8	8	2.5	3.5088	4000	2850	H2O&CO2&O3&CH4
	18	9	7	3.5088	4	2850	2500	H2O&CO2&Ch4

LW	Bands			Wavelength (Micron)		Wavenumber(cm-1)		
	Band#	Alternate Band#	#K's	Begin	End	Beg	End	Gases
	1	10	2	4.54	5.26	2200	1900	H2O
	2	11	3	5.26	5.88	1900	1700	H2O
	3	12	4	5.88	7.14	1700	1400	H2O
	4	13	4	7.14	8	1400	1250	H2O&CH4&N2O
	5	14	3(9)	8	9.09	1250	1100	H2O&CH4&N2O&Cfc
	6	15	5(8)	9.09	10.2	1100	980	H2O&O3&Cfc
	7	16	2(2)	10.2	12.5	980	800	H2O&Cfc
	8	17	10	12.5	14.9	800	670	H2O&CO2
	9	18	12	14.9	18.5	670	540	H2O&O2
	10	19	7	18.5	25	540	400	H2O
	11	20	7	25	35.7	400	280	H2O
	12	21	8	35.7	Inf	280	0	H2O
LW	Hidden	Bands						
	13	22	5	4.54	4	2200	2500	H2O&N2O&CO2
	14	23	5	4	3.5	2500	2850	H2O&CO2

Aerosol Type:

Aerosol type is used to determine the spectral normalized extinction, scattering and absorption properties of the aerosol. 25 aerosol types are featured from these sources.

- d'Almedia (Types 1-3)
- Tegin&Lacis (Types 4-8)
- OPAC Version 3.1a (Types 9-18)
- Lacis 2004 (Types 19-25)

1. Maritime (8 sets of RH dependent properties)
2. Continental (8 sets of RH dependent properties)
3. Urban (8 sets of RH dependent properties)
4. 0.5 Micron Mineral_Dust
5. 1.0 Micron Mineral_Dust
6. 2.0 Micron Mineral_Dust
7. 4.0 Micron Mineral_Dust
8. 8.0 Micron Mineral_Dust
9. 'inso' Insoluble
10. 'waso' Water Soluble (8 sets of RH dependent properties)
11. 'soot' Soot
12. 'ssam' Sea Salt (Accumulation Mode) (8 sets of RH dependent properties)
13. 'sscm' Sea Salt (Coarse Mode) (8 sets of RH dependent properties)
14. 'minm', Mineral Dust (Nucleation Mode)
15. 'miam', Mineral Dust (Accumulation Mode)
16. 'micm' Mineral Dust (Coarse Mode)
17. 'mitr' Mineral Dust (Transported Mode)
18. 'suso' Sulfate Droplets (8 sets of RH dependent properties)
19. 0.5 Micron Mineral_Dust (Lacis 2004)
20. 1.0 Micron Mineral_Dust (Lacis 2004)
21. 2.0 Micron Mineral_Dust (Lacis 2004)
22. 4.0 Micron Mineral_Dust (Lacis 2004)
23. 8.0 Micron Mineral_Dust (Lacis 2004)
24. [0.1-0.5]um bin of LogNorm Dist to Lacis Dust for re=0.298 sig=2
25. [0.5-5.0]um bin of LogNorm Dist to Lacis Dust for re=0.298 sig=2

```
README Ed4_LaRC_FuLiou          Jan 7th 2015  fred.g.rose@nasa.gov

Once you have downloaded the Fuliou distribution..

1) Uncompress using : gzip -d Ed4_LaRC_FuLiou20150106.tar.gz

2) Untar using : tar -xvf Ed4_LaRC_FuLiou20150106.tar

3) Change directory into  Ed4_LaRC_FuLiou20150106

4) Set up environment variables to compile F90 and F77 source code.


An "example" on a unix computer with a gfortran compiler would be..

 setenv F90COMP " -O2 -c "

 setenv FCOMP " -O2 -c"

 setenv F90 /usr/local/bin/gfortran

 setenv F77 /usr/local/bin/gfortran


5) Familiarize with the directory structure

 The actual radiative transfer F90 source code is under ./lib/src

 Once the make file is run an object library is created as
./lib/libEd3Fu_201212.a

 F90 .mod files are created under ./lib/mod

 An example code to show how to setup inputs is under
./src/simple/simple.f90

 Example inputs of  standard atmosphere temperature and humidity
./testatms


6)From the top level directory type:  make


This should

  A) Compile the code library under ./lib/src

  B) Compile the example code .src/simple.f90

  C) Execute the example code executible ./src/simple



(You should see something like the following.)
```

```
>/Users/rose/fuliou/Ed4_LaRC_FuLiou/Ed4_LaRC_FuLiou20150106 make
cd ./lib/src ;make
/usr/local/bin/gfortran  -O2 -c     extras.f90
/usr/local/bin/gfortran  -O2 -c     taucorr.f90
/usr/local/bin/gfortran  -O2 -c     fuinput.f90
/usr/local/bin/gfortran  -O2 -c     fuoutput.f90
/usr/local/bin/gfortran  -O2 -c     fuprint.f90
/usr/local/bin/gfortran  -O2 -c     entropy_lw.f90
/usr/local/bin/gfortran  -O2 -c     icedirsfc.f90
/usr/local/bin/gfortran  -O2 -c     ma_tip.f90
/usr/local/bin/gfortran  -O2 -c     qsortd.f90
/usr/local/bin/gfortran  -O2 -c     vla.f90
/usr/local/bin/gfortran  -O2 -c     uvcor_all.f90
/usr/local/bin/gfortran  -O2 -c     rad_multi_200511.f90
/usr/local/bin/gfortran  -O2 -c     seiji_k2d.f90
/usr/local/bin/gfortran  -O2 -c     seiji_solver_200511.f90
/usr/local/bin/gfortran  -O2 -c     gflq.f90
/usr/local/bin/gfortran  -O2 -c     calipso_output.f90
/usr/local/bin/gfortran  -O2 -c     zjin.f90
/usr/local/bin/gfortran  -O2 -c     ar_asy.f90
/usr/local/bin/gfortran  -O2 -c    aqua_wnflt_0404.f
/usr/local/bin/gfortran  -O2 -c    misc_200511.f
/usr/local/bin/gfortran  -O2 -c    cloud_optics.f
/usr/local/bin/gfortran  -O2 -c    seiji_twostreamsolv_sw_v20.f
seiji_twostreamsolv_sw_v20.f:168.48:

     &      af_clear,bf_clear,ef_clear,ak_clear,u1i,u1s,
                                                1
```

```
Warning: Type mismatch in argument 'u1i' at (1); passed REAL(8) to
REAL(4)

/usr/local/bin/gfortran  -O2 -c    aerosols_200511.f

ar -rcv libEd3Fu_201212.a  extras.o fuinput.o fuoutput.o fuprint.o
entropy_lw.o icedirsfc.o ma_tip.o qsortd.o vla.o rad_multi_200511.o
seiji_k2d.o seiji_solver_200511.o taucorr.o uvcor_all.o gflq.o
calipso_output.o zjin.o ar_asy.o aqua_wnflt_0404.o   misc_200511.o
cloud_optics.o    seiji_twostreamsolv_sw_v20.o aerosols_200511.o

a - extras.o

a - fuinput.o

a - fuoutput.o

a - fuprint.o

a - entropy_lw.o

a - icedirsfc.o

a - ma_tip.o

a - qsortd.o

a - vla.o

a - rad_multi_200511.o

a - seiji_k2d.o

a - seiji_solver_200511.o

a - taucorr.o

a - uvcor_all.o

a - gflq.o

a - calipso_output.o

a - zjin.o

a - ar_asy.o

a - aqua_wnflt_0404.o

a - misc_200511.o

a - cloud_optics.o

a - seiji_twostreamsolv_sw_v20.o

a - aerosols_200511.o

\cp *.mod ../mod

\cp libEd3Fu_201212.a  ../
```

```
cd ./src/simple ; make

/usr/local/bin/gfortran  -O2 -c  -I ../../lib/mod   simple.f90

/usr/local/bin/gfortran  -o simple simple.o ../../lib/libEd3Fu_201212.a

cd ./src/simple ; ./simple
```

```
==========================================================================================

 Fu-Liou Model inputs in structure fi%  Begin

 # of Model LAYERS      :          34

 Solver Config Modes    : T T T T

 Curved Earth Airmass Co: T

 nirold Ray,Ice,Wat,Gas,Kwc : F F F F F

 Solar Constant (wm-2)  :   1365.0000

 Cosine Solar Zenith    :   1.0000000

 Cosine View Zenith     :  0.80000001

 fu%txt                 :           0

      Spect Emissivity        : 0.990 0.990 0.990 0.990 0.990 0.990 0.990 0.990 0.990
0.990 0.990 0.990

 Skin Temperture (k)    :   294.00000

 Trace Gas Concentration__________________________________________________________

 CO2 Conc (ppmv)        :   360.00000

 CH4 Conc (ppmv)        :   1.7500000

 N2O Conc (ppmv)        :  0.31000000

 CFCs Conc (ppv)        :  2.68000011E-10  5.02999975E-10  1.05000002E-10

 Option Selection_________________________________________________________________

 >4 micron solar lband6a:     T

   Continuum option sel       :     5

 # of LW bands >2200cm-1:     2

 Hybrid solver option   :     T

 Solver option          :     1

      Window instrument       :     0

 Fourstream Sol fourssl :     F

 Fourstream IR  foursir :     F

 Cloud lwc profile flag :     2

 Aerosols__________________________________________________________________________
```

```
 #Aerosol Taus        :           1

 #Aerosol Constituents :          2

Aer.Wavelength(s)(micron)   0.641

 -Aerosol Type               :           2

Aer. Optical Depth(s)     0.80000

 -Aerosol Type               :           1

Aer. Optical Depth(s)     0.20000

 Profiles______________________________________________________________________

 Level.Pres(hPa).Temp(K).H20(g/g).RH(%)..O3(g/g)...AOT%PROFILES

     1      0.10   226.21 2.60E-06   0.0 1.20E-06  0.00  0.00

     2      0.21   243.34 2.79E-06  -0.0 2.02E-06  0.00  0.00

     3      0.47   260.47 2.99E-06  -0.0 2.84E-06  0.00  0.00

     4      0.87   274.01 3.14E-06  -0.0 3.49E-06  0.00  0.00

     5      1.63   270.72 3.10E-06  -0.0 5.47E-06  0.00  0.00

     6      3.17   258.93 2.97E-06   0.0 8.86E-06  0.00  0.00

     7      6.37   245.46 2.82E-06   0.0 9.90E-06  0.00  0.00

     8     13.21   233.99 2.69E-06   0.0 1.02E-05  0.00  0.00

     9     19.03   229.07 3.33E-06   0.1 8.59E-06  0.00  0.00

    10     27.86   223.96 3.99E-06   0.4 6.94E-06  0.01  0.01

    11     41.08   220.82 3.98E-06   0.9 5.43E-06  0.04  0.04

    12     60.79   217.86 3.98E-06   1.9 3.48E-06  0.03  0.03

    13     70.00   216.95 3.98E-06   2.5 2.83E-06  0.08  0.08

    14     90.27   216.00 4.00E-06   3.7 1.75E-06  0.30  0.30

    15    134.06   216.00 4.02E-06   5.5 8.73E-07  0.81  0.81

    16    196.98   219.71 1.44E-05  17.8 4.25E-07  0.05  0.05

    17    200.00   220.30 1.57E-05  18.4 4.10E-07  2.02  2.02

    18    283.31   235.40 1.60E-04  44.2 2.14E-07  1.53  1.53

    19    326.26   242.30 2.60E-04  39.3 1.83E-07  2.16  2.16

    20    374.44   248.34 4.13E-04  38.6 1.50E-07  1.36  1.36

    21    400.00   251.75 5.28E-04  37.6 1.39E-07  1.67  1.67

    22    428.11   255.22 6.49E-04  29.7 1.28E-07  4.20  4.20

    23    487.95   261.09 9.44E-04  30.3 1.06E-07  0.96  0.96

    24    500.00   262.23 1.03E-03  30.9 1.03E-07  4.84  4.84

    25    554.50   267.04 1.39E-03  31.8 9.12E-08  7.94  7.94
```

```
   26   628.32   273.02 2.36E-03  39.1 7.98E-08 10.78 10.78

   27   709.97   279.00 3.87E-03  47.2 6.99E-08  6.86  6.86

   28   754.70   282.01 4.92E-03  51.8 6.56E-08  7.88  7.88

   29   801.14   284.95 5.95E-03  54.5 6.13E-08  9.15  9.15

   30   850.00   287.47 7.26E-03  59.7 5.83E-08 10.71 10.71

   31   901.78   289.99 8.58E-03  63.5 5.54E-08 12.41 12.41

   32   956.21   292.01 1.01E-02  70.0 5.27E-08  8.30  8.30

   33   989.89   293.20 1.11E-02  73.3 5.11E-08  2.94  2.94

   34  1001.38   293.60 1.14E-02  74.3 5.05E-08  2.97  2.97

   35  1012.76   293.99 1.17E-02  75.3 5.00E-08  0.00  0.00

 Spectral Surface Albedo WITH AEROSOLS::

    Spect Surface albedo:w/AOT CLEAR  0    0.000 0.000 0.000 0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

    Spect Surface albedo:w/AOT Cloud  1    0.000 0.000 0.000 0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

 Spectral Surface Albedo WITHOUT Aerosol::

    Spect Surface albedo:NOAOT CLEAR  0    0.000 0.000 0.000 0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

    Spect Surface albedo:NOAOT Cloud  1    0.000 0.000 0.000 0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

================================================================================

  CLOUDS::    1       1

    Fractions :   1.000

    DPI   mode:       F

    #Overlaps :       1

-------------------------

    Opt Depth :  10.000

    RPhase    :    2.00

    Re        :   15.00

    De        :   60.00

  Top:Bot Lay#:  17  20

  Top:Bot Pres: 200 400

    Nu .......:     0.0

    Mn_lin_tau:    11.5

 Fu-Liou Model inputs in structure fi%  End
```

```
==========================================================================================
===============================

                      SHORTWAVE Down---------------    Shortwave Up------------------

 #  Presure  Height  Clear   Prist   Total  TotNOA    Clear   Prist   Total  TotNOA

Lev  [hPa] [meters]   Down    Down    Down    Down      Up      Up      Up      UP

  1    0.10  66295. 1365.03 1365.03 1365.03 1365.03  139.24   51.95  590.23  561.83

  2   70.00  18904. 1330.89 1330.14 1331.54 1331.35  140.04   50.45  597.33  568.19

  3  200.00  12241. 1316.23 1315.08 1320.75 1320.33  136.55   45.08  600.64  569.63

  4  500.00   5780. 1226.03 1237.43  611.71  580.64  119.38   29.94   88.69   16.12

  5  850.00   1502. 1036.95 1117.80  497.63  527.49   62.56   10.01   38.19    4.67

  6 1012.76      2.  909.80 1063.17  426.23  501.17    0.00    0.00    0.00    0.00

                     LONGWAVE Down----------------    Longwave  Up------------------

 #  Presure  Height  Clear   Prist   Total  TotNOA    Clear   Prist   Total  TotNOA

Lev  [hPa] [meters]   Down    Down    Down    Down      Up      Up      Up      UP

  1    0.10  66295.    0.00    0.00    0.00    0.00  274.78  278.82  147.73  147.79

  2   70.00  18904.   13.33   13.31   13.33   13.31  273.43  277.56  143.86  143.92

  3  200.00  12241.   27.94   27.68   27.91   27.68  281.18  285.18  146.42  146.43

  4  500.00   5780.  141.41  139.23  238.17  238.00  332.24  334.67  332.66  334.81

  5  850.00   1502.  289.57  283.92  331.75  329.39  400.24  400.64  400.46  400.80

  6 1012.76      2.  356.46  350.81  380.75  377.83  422.72  422.66  422.96  422.93

                     WINDOW Down------------------    WINDOW  Up--------------------

 #  Presure  Height  Clear   Prist   Total  TotNOA    Clear   Prist   Total  TotNOA

Lev  [hPa] [meters]   Down    Down    Down    Down      Up      Up      Up      UP

  1    0.10  66295.    0.00    0.00    0.00    0.00  101.87  104.72   30.18   30.20

  2   70.00  18904.    1.65    1.65    1.65    1.65  103.45  106.39   29.49   29.51

  3  200.00  12241.    2.03    1.97    2.01    1.97  107.05  109.98   29.90   29.91

  4  500.00   5780.    5.09    4.06   52.37   52.27  111.64  113.57  111.99  113.71

  5  850.00   1502.   30.80   26.15   65.34   63.36  118.92  119.25  119.12  119.41

  6 1012.76      2.   62.49   57.32   84.72   82.04  121.54  121.48  121.76  121.73

STOP  Simple.f90 normal end
```