Radiative Transfer for Energetics

Rapid Radiative Transfer Model - for GCMs - Parallel

RTE-RRTMGP in CAM implementation status

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with input and help from:
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+ EarthWorks SE group, & R. Pincus

AMWG, January 2023

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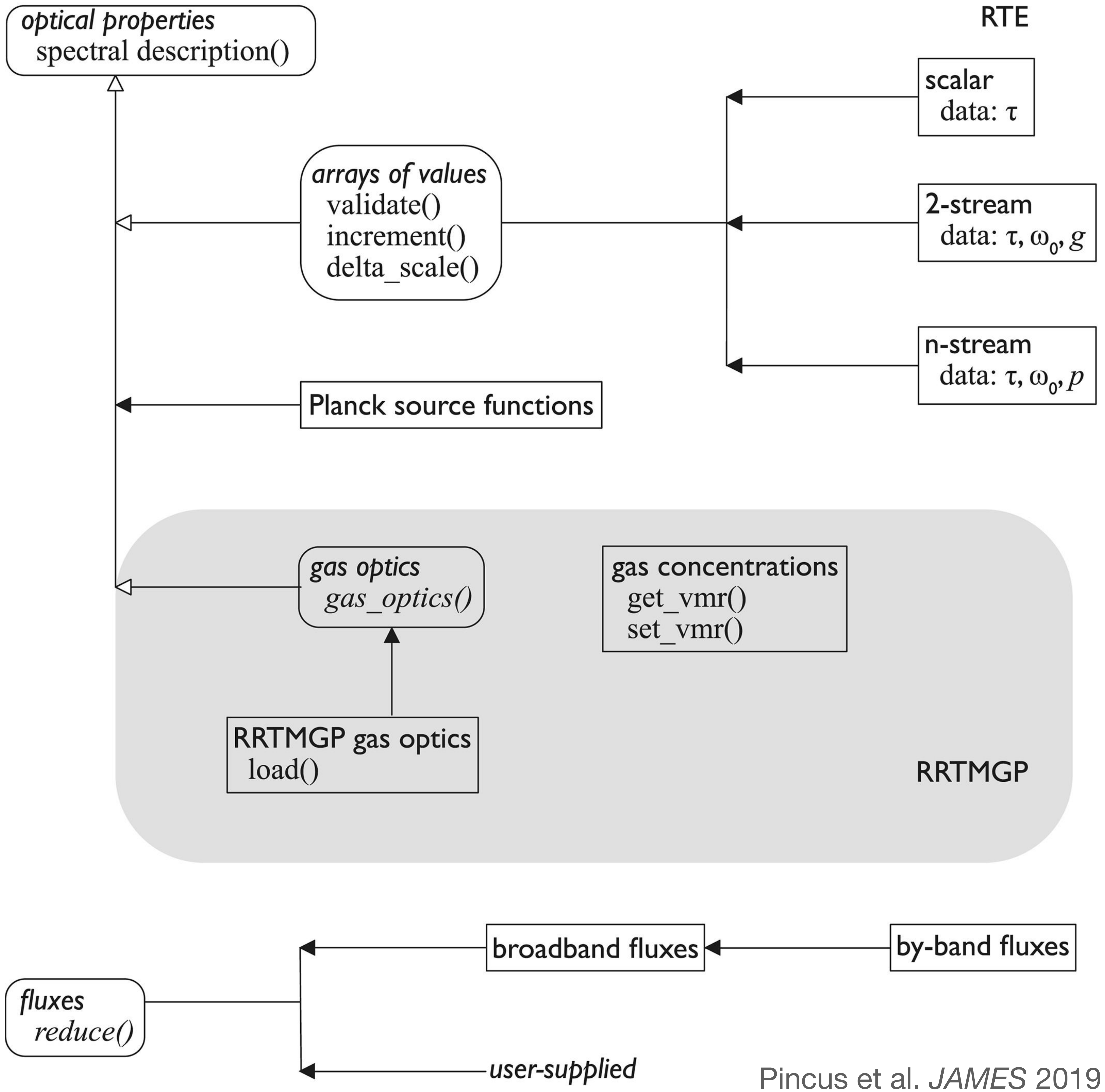
catalyst

What & Why of RRTMGP

- Rewrite of RRTMG (Fortran 2003)
  - still a plane-parallel, correlated-k, 2-stream RTM
  - uses classes to control information passing (no reading/writing files)
  - **no assumption of vertical ordering**
  - **updated spectroscopy**
  - Shortwave solver: $f(K_{SW}, \text{insolation}(\lambda), \alpha_{direct}, \alpha_{diffuse},)$
  - Longwave solver: $f(K_{LW}, B(\lambda, \text{lev}), \varepsilon_{sfc})$

- Flexibility — extensible, but comes at a slight increase of work on user end

- Future capabilities
  - GPU



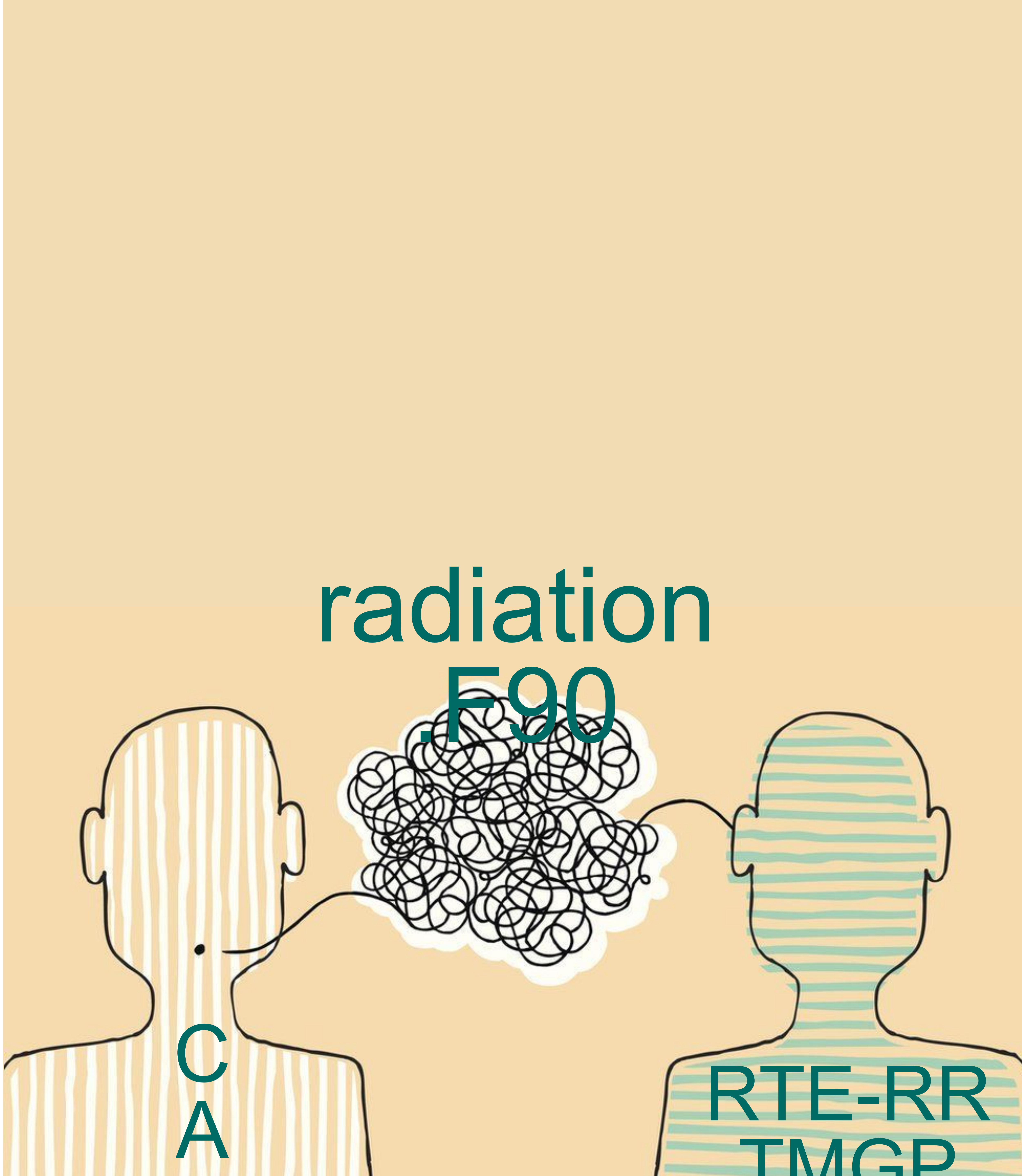
Pincus et al. *JAMES* 2019

What’s involved

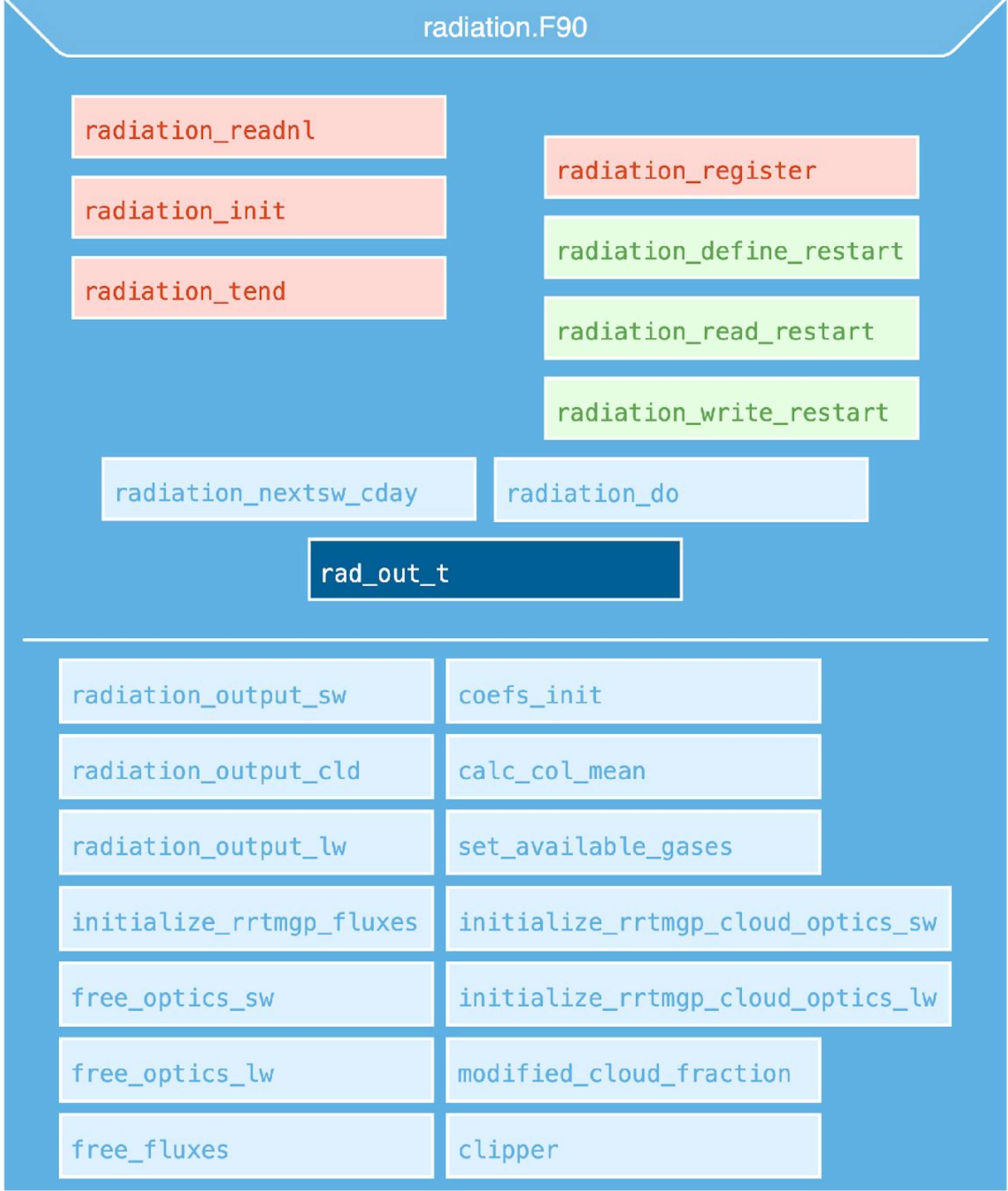
- Bring in RTE-RRTMGP as an external
- new interface between CAM and RTE-RRTMGP

  based on B. Eaton’s old version, close to CAM6

  with inspiration from B. Hillman’s E3SM version
- Mainly this is **radiation.F90**,
  but with a bunch of supporting changes:
  - rrtmgp_inputs.F90
    (new, similar to rrtmg_state.F90)
  - radconstants.F90
  - cloud_rad_props.F90
  - rrtmgp_driver.F90
    (new, heavily based on
    mo_rrtmgp_clr_all_sky.F90 in “extensions”)



interface structure



radiation.F90

radiation_readnl

radiation_init

radiation_tend

radiation_register

radiation_define_restart

radiation_read_restart

radiation_write_restart

radiation_nextsw_cday

radiation_do

rad_out_t

radiation_output_sw

coefs_init

radiation_output_cld

calc_col_mean

radiation_output_lw

set_available_gases

initialize_rrtmgp_fluxes

initialize_rrtmgp_cloud_optics_sw

free_optics_sw

initialize_rrtmgp_cloud_optics_lw

free_optics_lw

modified_cloud_fraction

free_fluxes

clipper

radiation_tend

Preparation

Determine time (do radiation?) and zenith angle (day/night)

rrtmgp_set_state

OUTPUT

T_{sfc}, ε_{sfc}, T, p, $\cos(\theta)$, α_{dif}, α_{dir}, TSI, TSI(g)

SHORTWAVE

determine cloud optical properties (SW)

combined liq + ice optical propertes; Add "snow cloud"; Add "graupel cloud"

Reorder bands for RRTMGP; Initialize and set RRTMGP cloud optical properties object

Set gases

Set aerosol optical properties; to RRTMGP object

call RTE_SW driver

SW output stage

LONGWAVE

determine cloud optical properties (LW)

combined liq + ice optical propertes; Add "snow cloud"; Add "graupel cloud"

Initialize and set RRTMGP cloud optical properties object

Set gases

Set aerosol optical properties; to RRTMGP object

call RTE_LW driver

LW output stage

Post-RT

Output

Radiative Heating

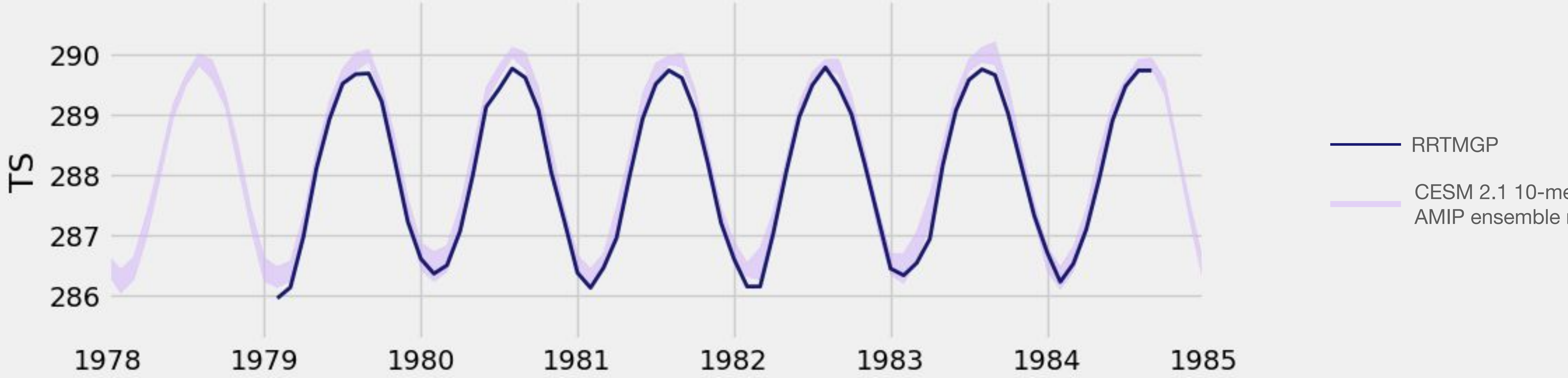
Deallocations

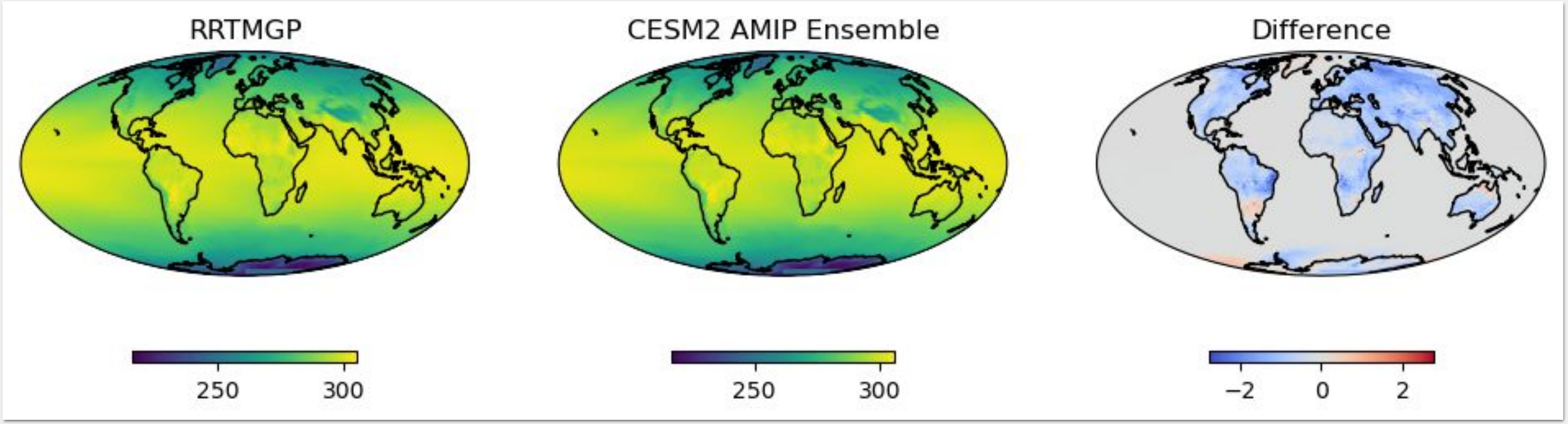
Where we were

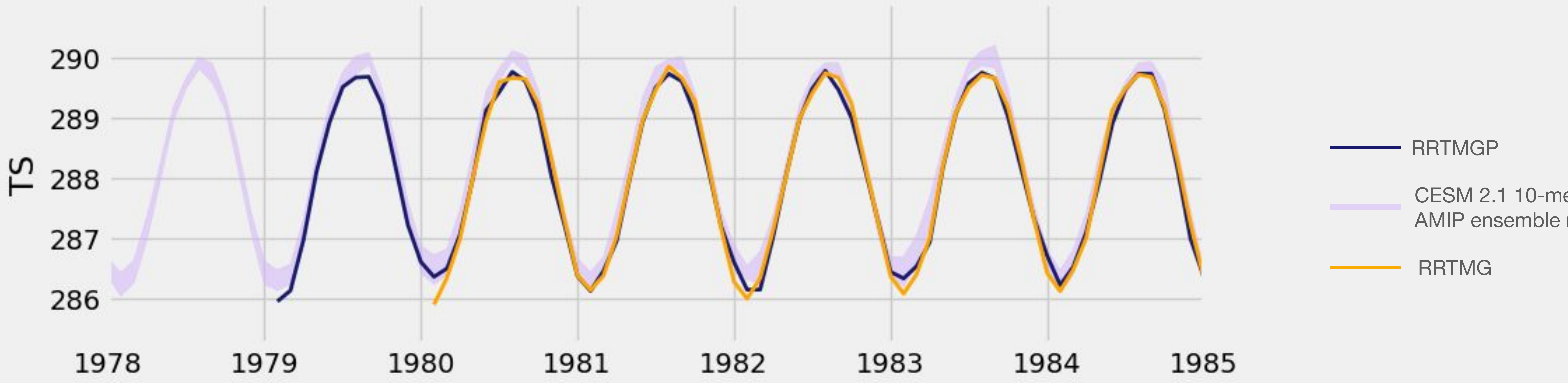
- Had moved to v1.4
- SCAM runs were completing, looking reasonable
- Global runs (FV 1°) were failing, appeared to be a memory issue

Current status

- RTE-RRTMGP v1.5, as “external” (v1.6 just released)
- Merged to very recent CAM tag
- xmlchange --append CAM_CONFIG_OPTS=“-rad rrtmgp”
- COSP available
- Test simulations
  - SCAM
  - QPC6 (FV & SE, I think)
  - F2000climo (FV 1°)
  - F2000climo (SE ne30)
  - F1850 (FV 2°, by Jiang Zhu)
  - FHIST (5y, FV 1°)
- Validation
  - Differences from CESM2-CAM6-FV (CMIP) simulations are clearly evident
    - Mix of radiation changes AND non-radiation development
  - Jiang Zhu noted SOLIN is less than in RRTMG, and QRL in lowest model level is pretty different


290
289
288
287
286
TS
1978
1979
1980
1981
1982
1983
1984
1985
RRTMGP
CESM 2.1 10-me
AMIP ensemble r


RRTMGP
CESM2 AMIP Ensemble
Difference
250
300
250
300
−2
0
2



TS
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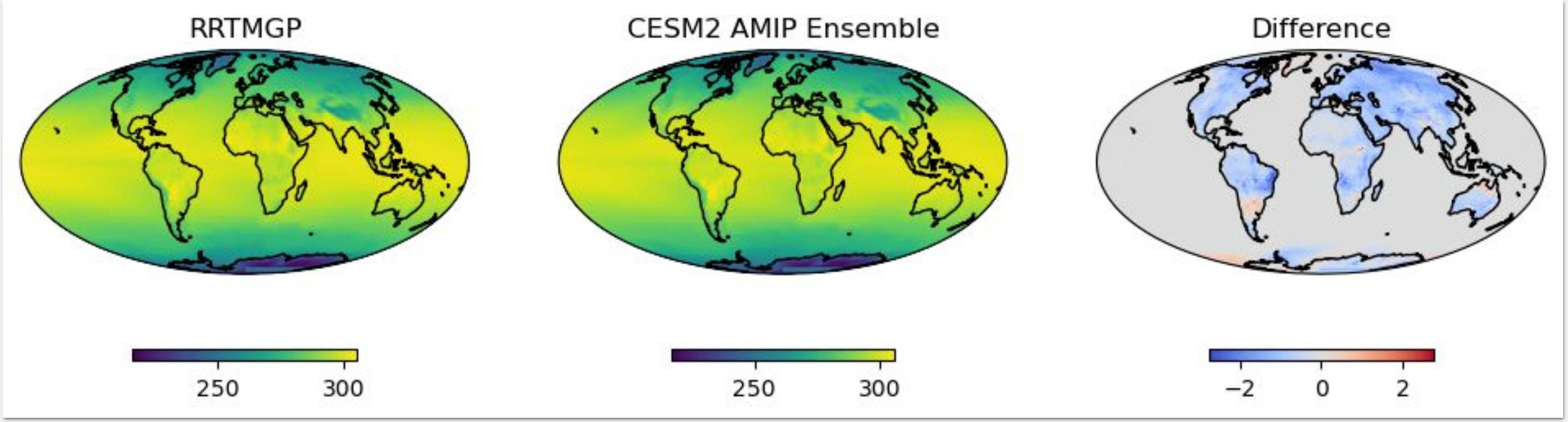
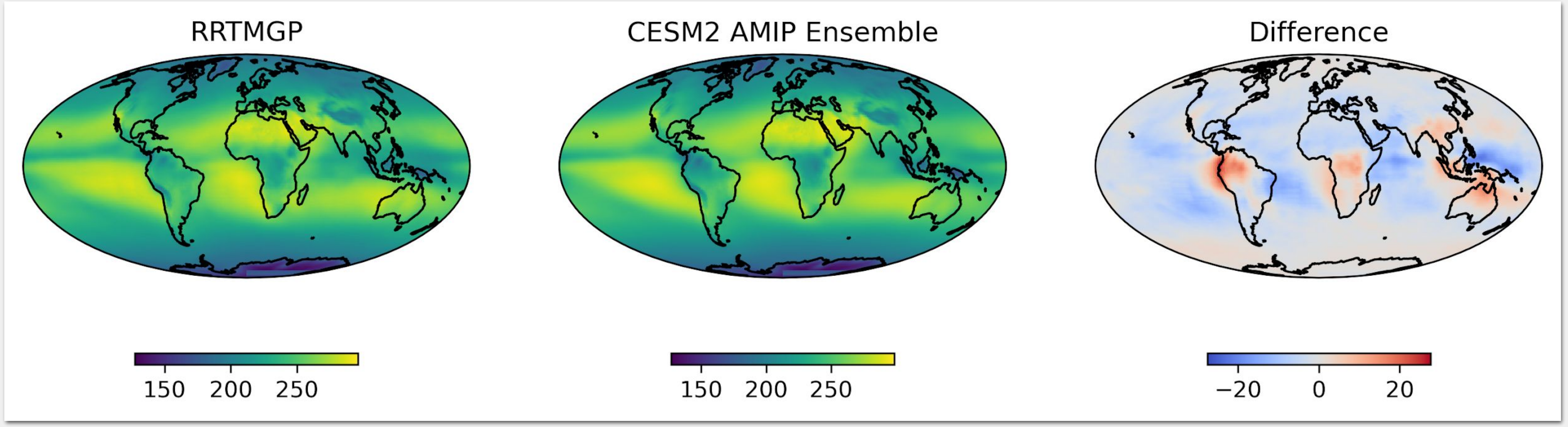
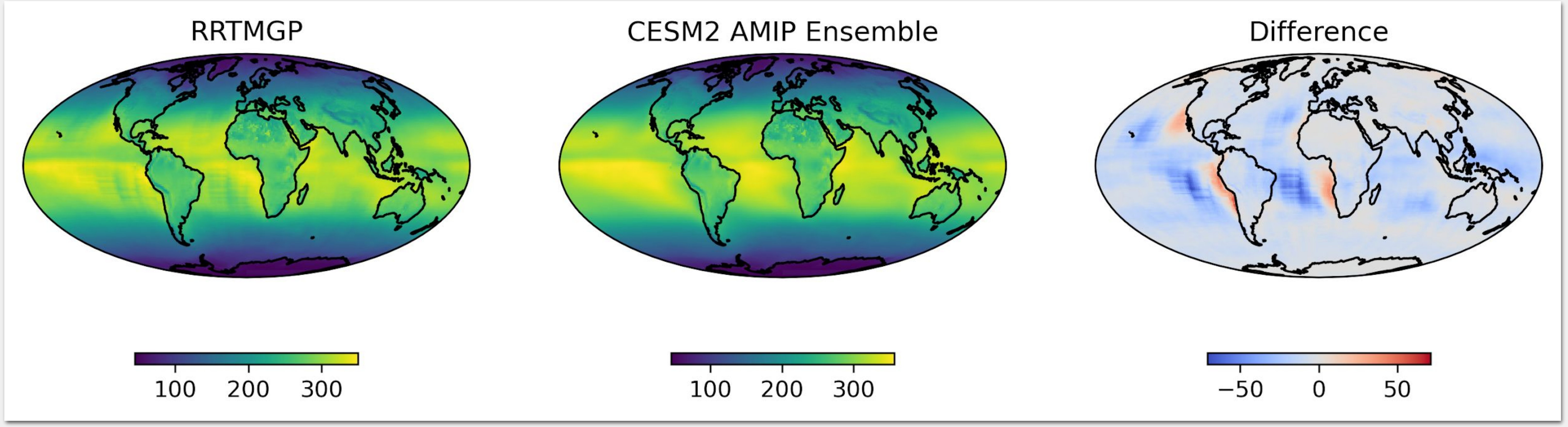
RRTMGP
CESM 2.1 10-me
AMIP ensemble r
RRTMG

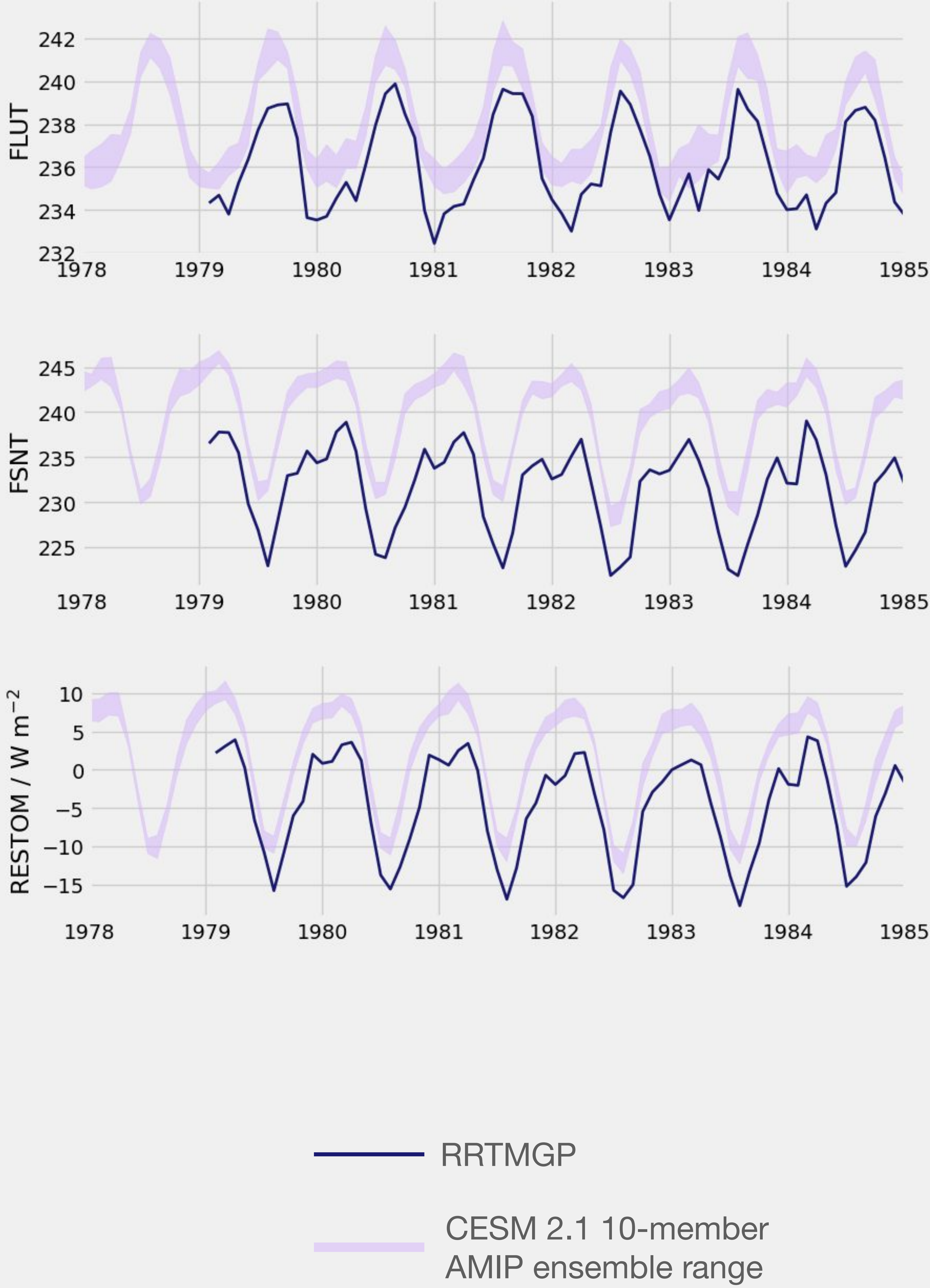


RRTMGP
CESM2 AMIP Ensemble
Difference
250
300
250
300
−2
0
2

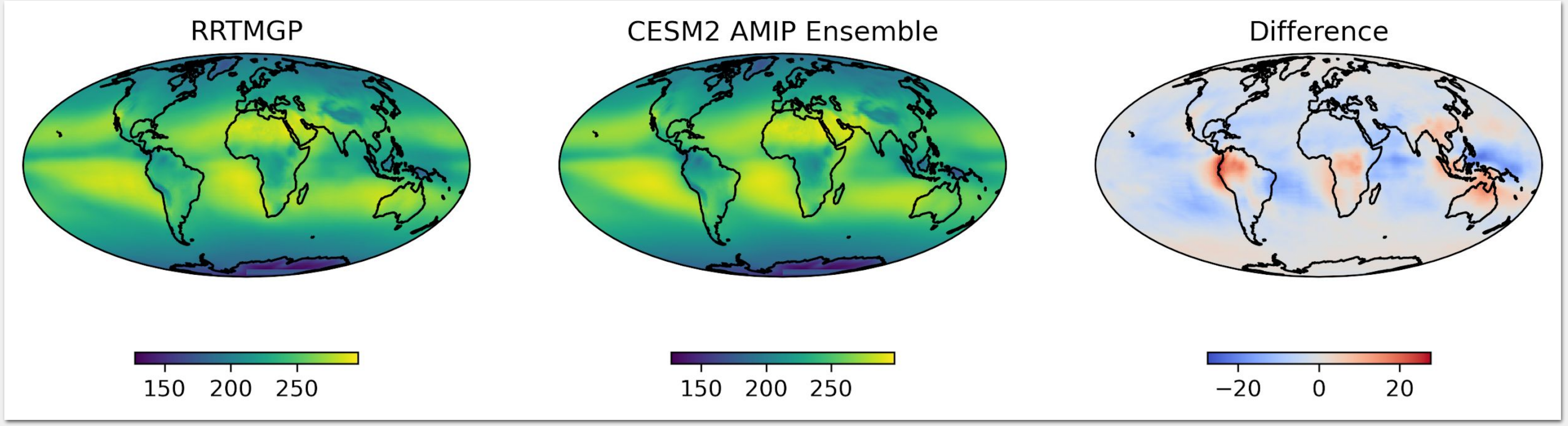
TOA fluxes

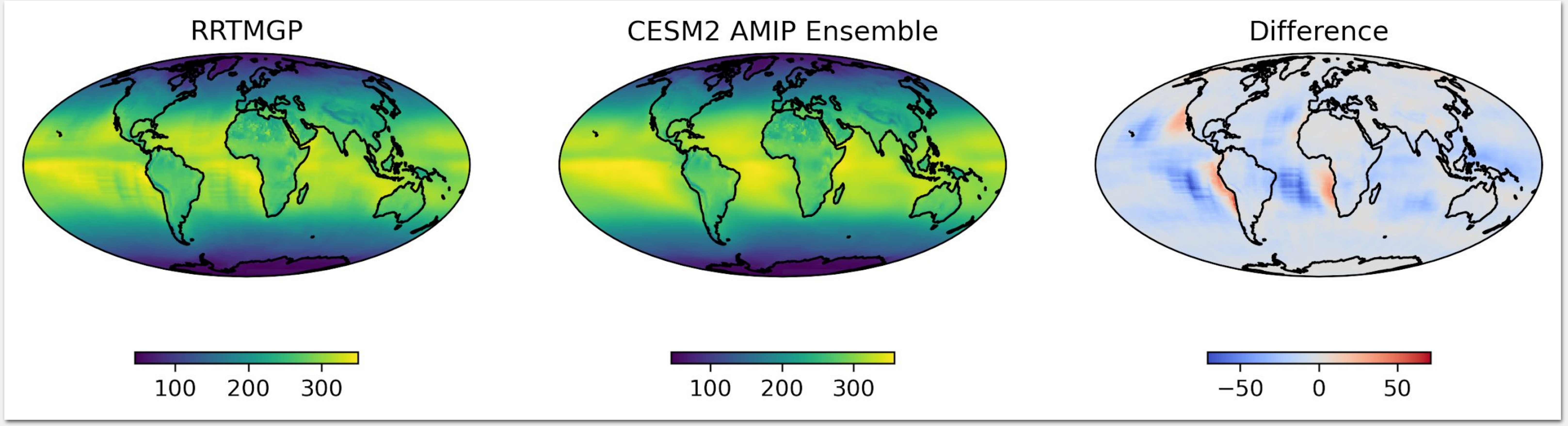

RRTMGP
CESM2 AMIP Ensemble
Difference
150
200
250
150
200
250
−20
0
20

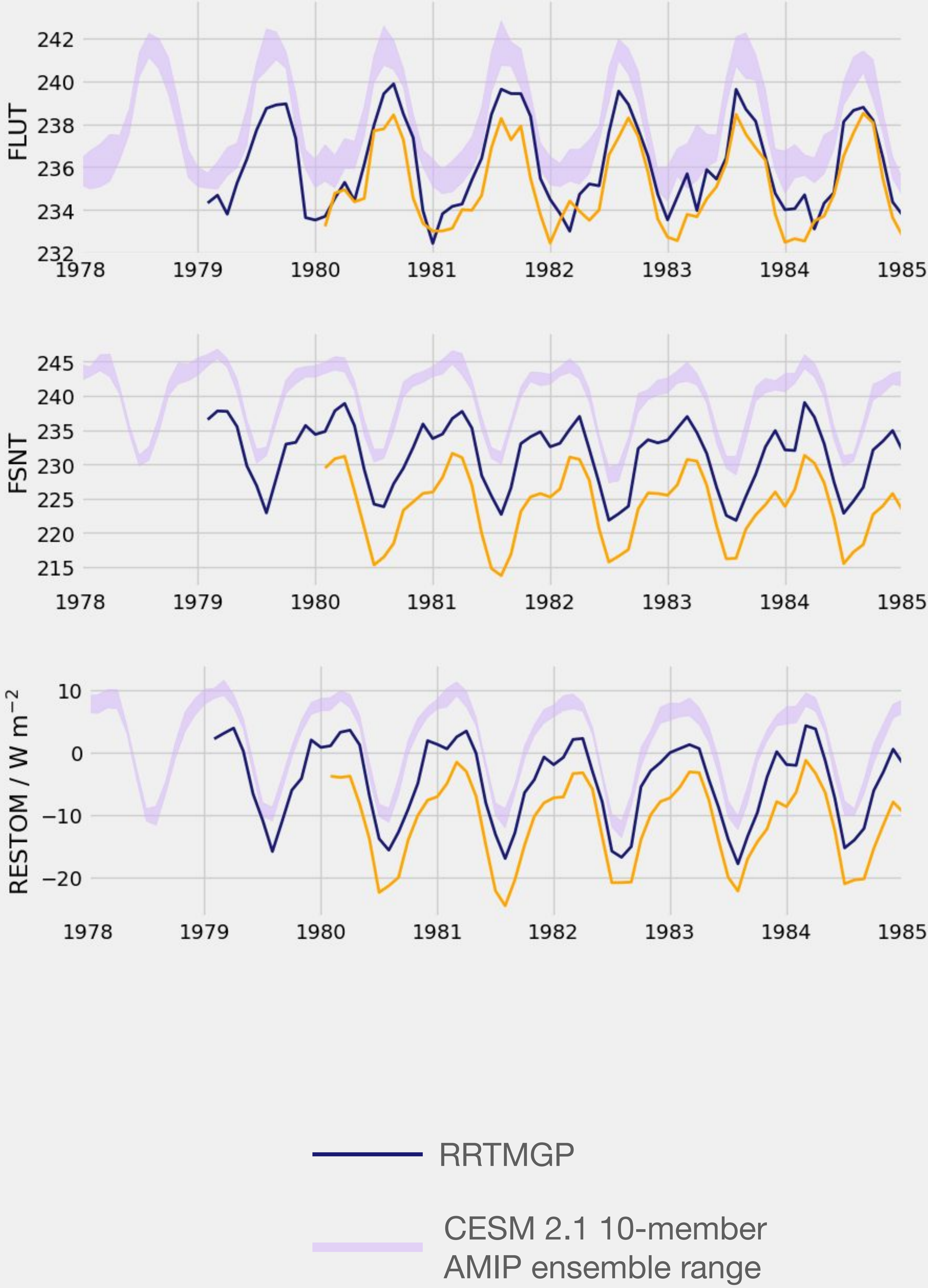

RRTMGP
CESM2 AMIP Ensemble
Difference
100
200
300
100
200
300
−50
0
50


FLUT
242
240
238
236
234
232
FSNT
245
240
235
230
225
RESTOM / W m⁻²
10
5
0
−5
−10
−15
1978
1979
1980
1981
1982
1983
1984
1985
RRTMGP
CESM 2.1 10-member
AMIP ensemble range

TOA fluxes


RRTMGP
CESM2 AMIP Ensemble
Difference
150
200
250
150
200
250
−20
0
20


RRTMGP
CESM2 AMIP Ensemble
Difference
100
200
300
100
200
300
−50
0
50


FLUT
242
240
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FSNT
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225
220
215
RESTOM / W m^{-2}
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−10
−20
1978
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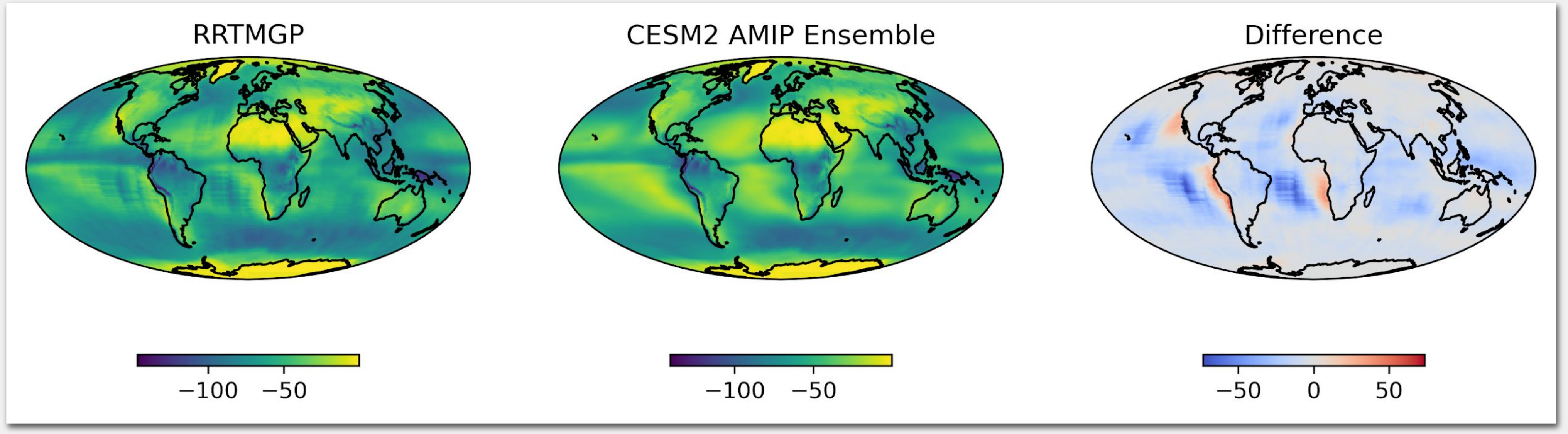
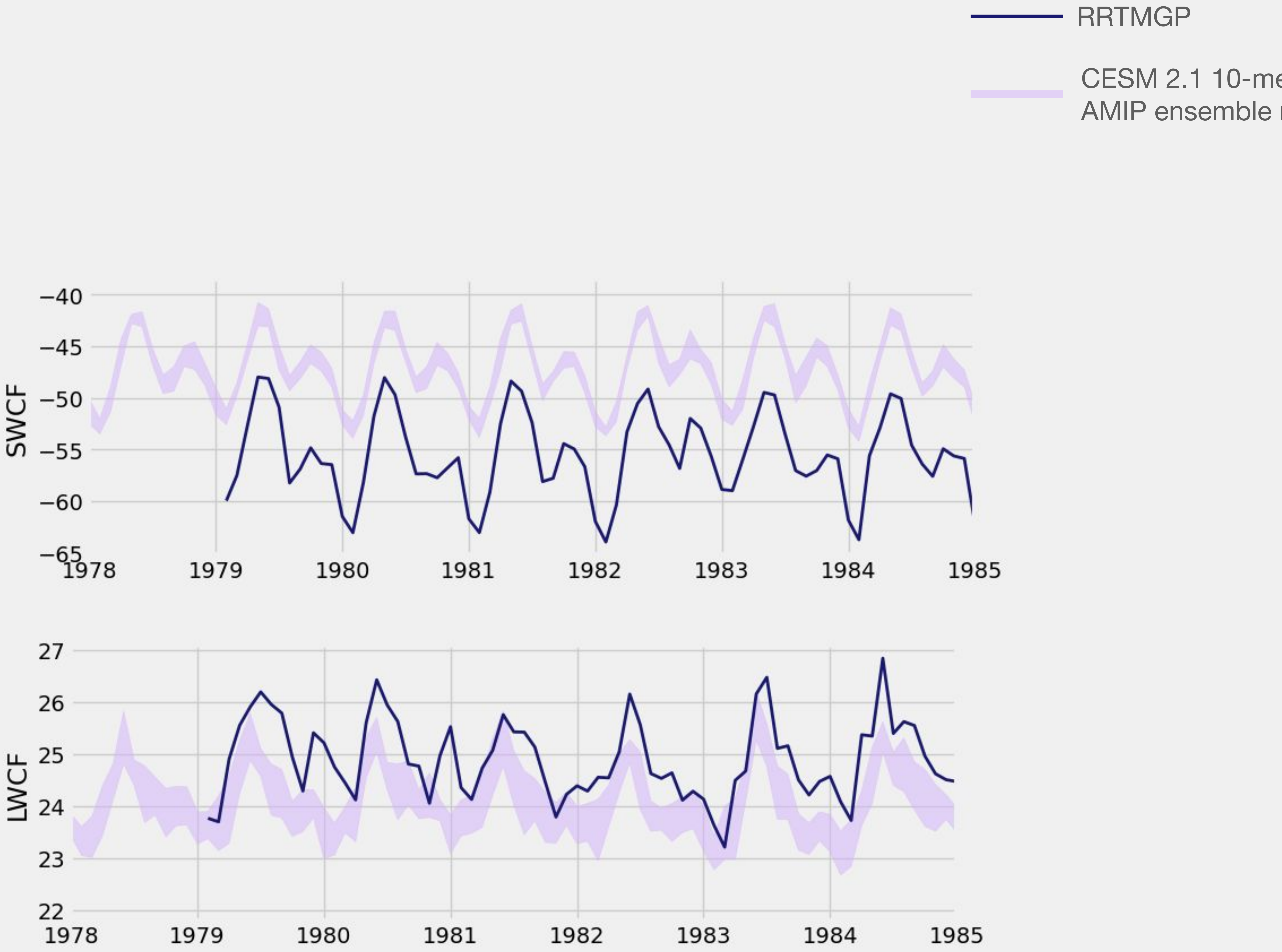
RRTMGP
CESM 2.1 10-member AMIP ensemble range


RRTMGP
CESM2 AMIP Ensemble
Difference
−100
−50
−100
−50
−50
0
50


RRTMGP
CESM 2.1 10-me
AMIP ensemble
SWCF
−40
−45
−50
−55
−60
−65
1978
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1981
1982
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1984
1985
LWCF
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1978
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1980
1981
1982
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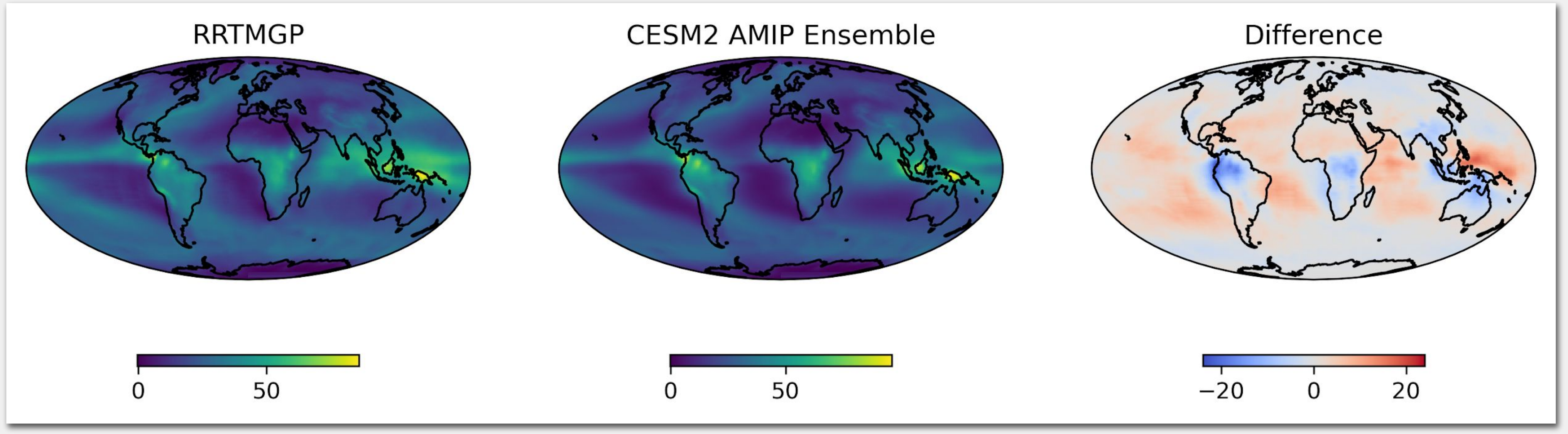
1984
1985


RRTMGP
CESM2 AMIP Ensemble
Difference
0
50
0
50
−20
0
20

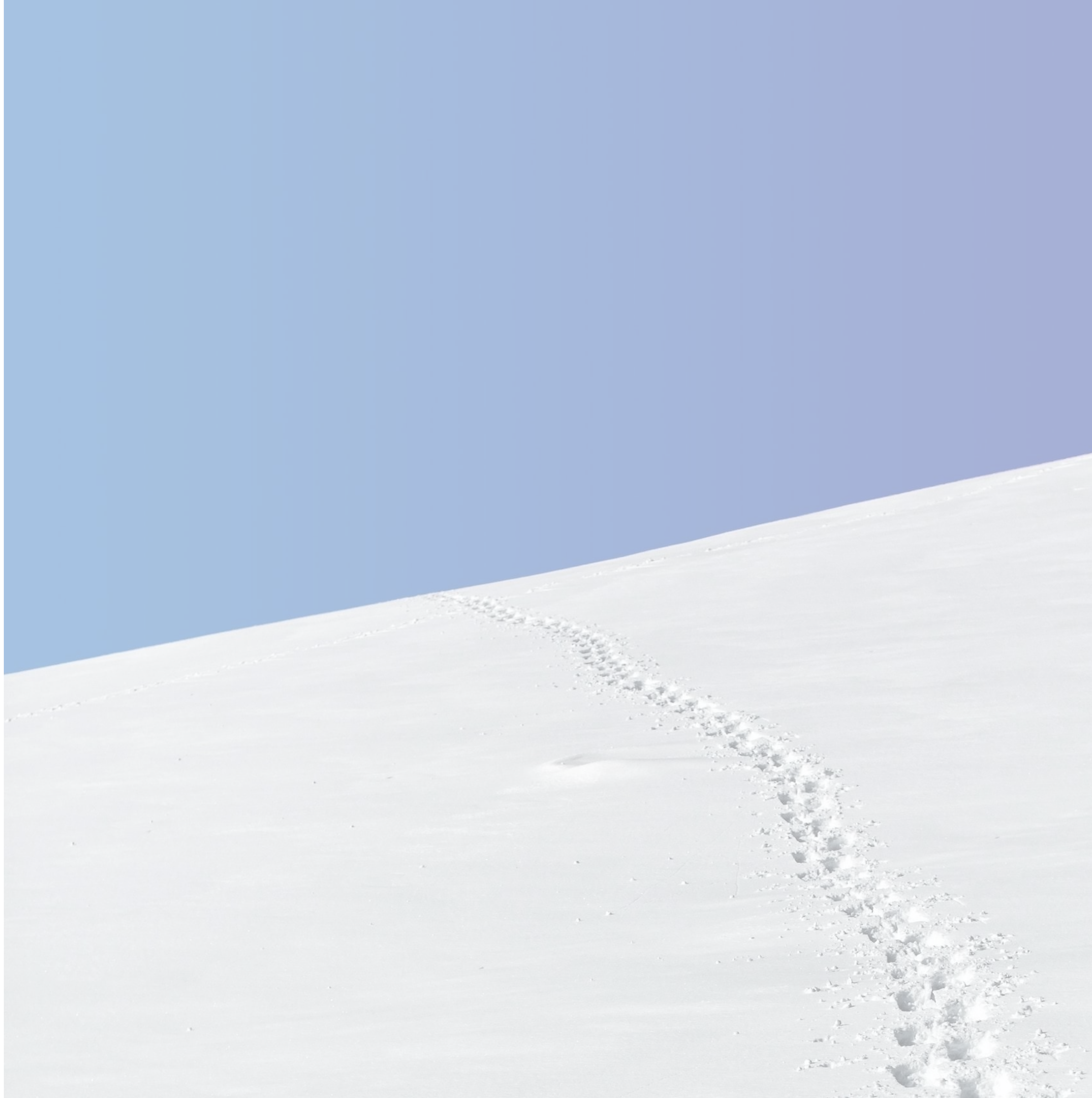
Next steps

- Get SOLIN to more closely match CAM6
- Diagnose QRL issue (maybe it’s better?)
- Work with CAM software engineers to make a PR to get RTE-RRTMGP on to the development branch *as an option*

copy coefficients files to CESM inputdata directory structure

introduce “compset” for regression testing

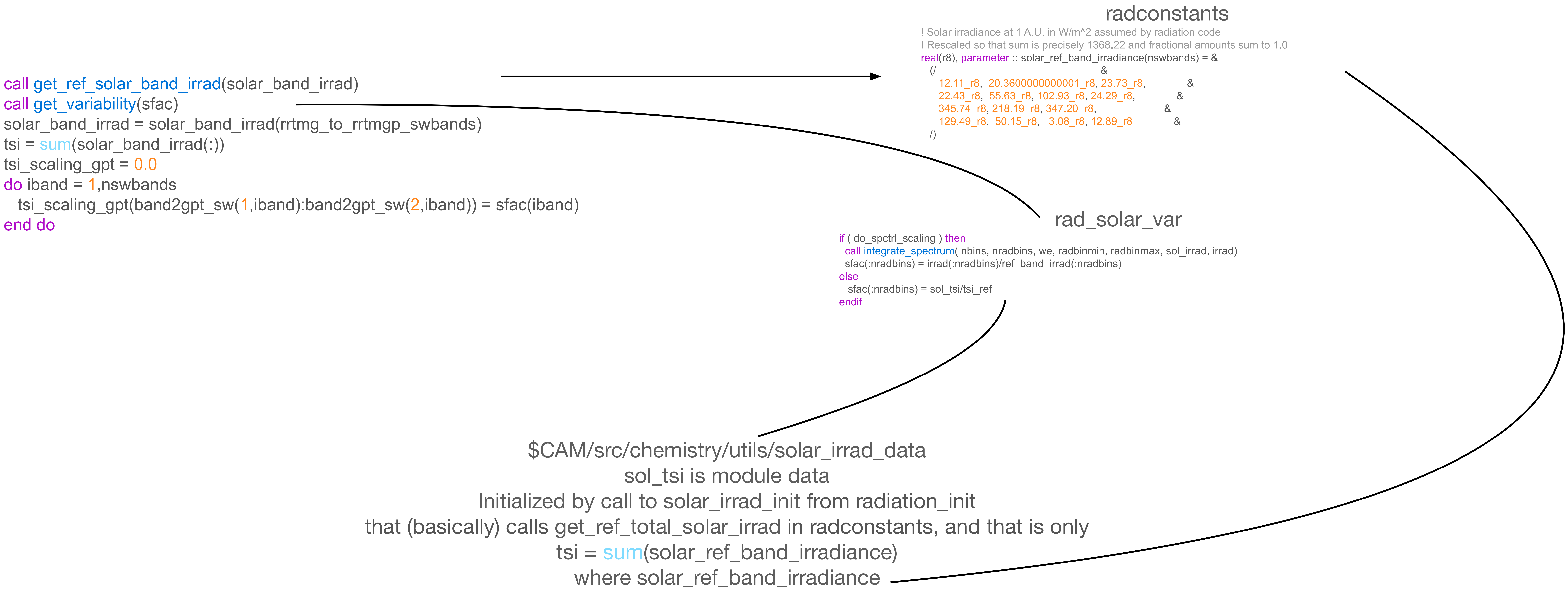
interface code review



Longer term

(help needed!)

- moving to CCPP version of RTE-RRTMGP (SIMA)
    - deconstruction of the new interface
        - optical properties will need to be packaged better
    - Liquid & Ice optical properties are based on lookup tables that are defined on RRTMG bands 😵
- utilizing GPU acceleration (EarthWorks)
- Switch to RTE-RRTMGP *as default* (and possibly only) radiation scheme
- There may be an opportunity to revisit the solar forcing to make it independent from the rest of the model
- The radconstants module still hard-codes some information, and ***should be eliminated***



```
call get_ref_solar_band_irrad(solar_band_irrad)
call get_variability(sfac)
solar_band_irrad = solar_band_irrad(rrtmg_to_rrtmgp_swbands)
tsi = sum(solar_band_irrad(:))
tsi_scaling_gpt = 0.0
do iband = 1,nswbands
  tsi_scaling_gpt(band2gpt_sw(1,iband):band2gpt_sw(2,iband)) = sfac(iband)
end do
```

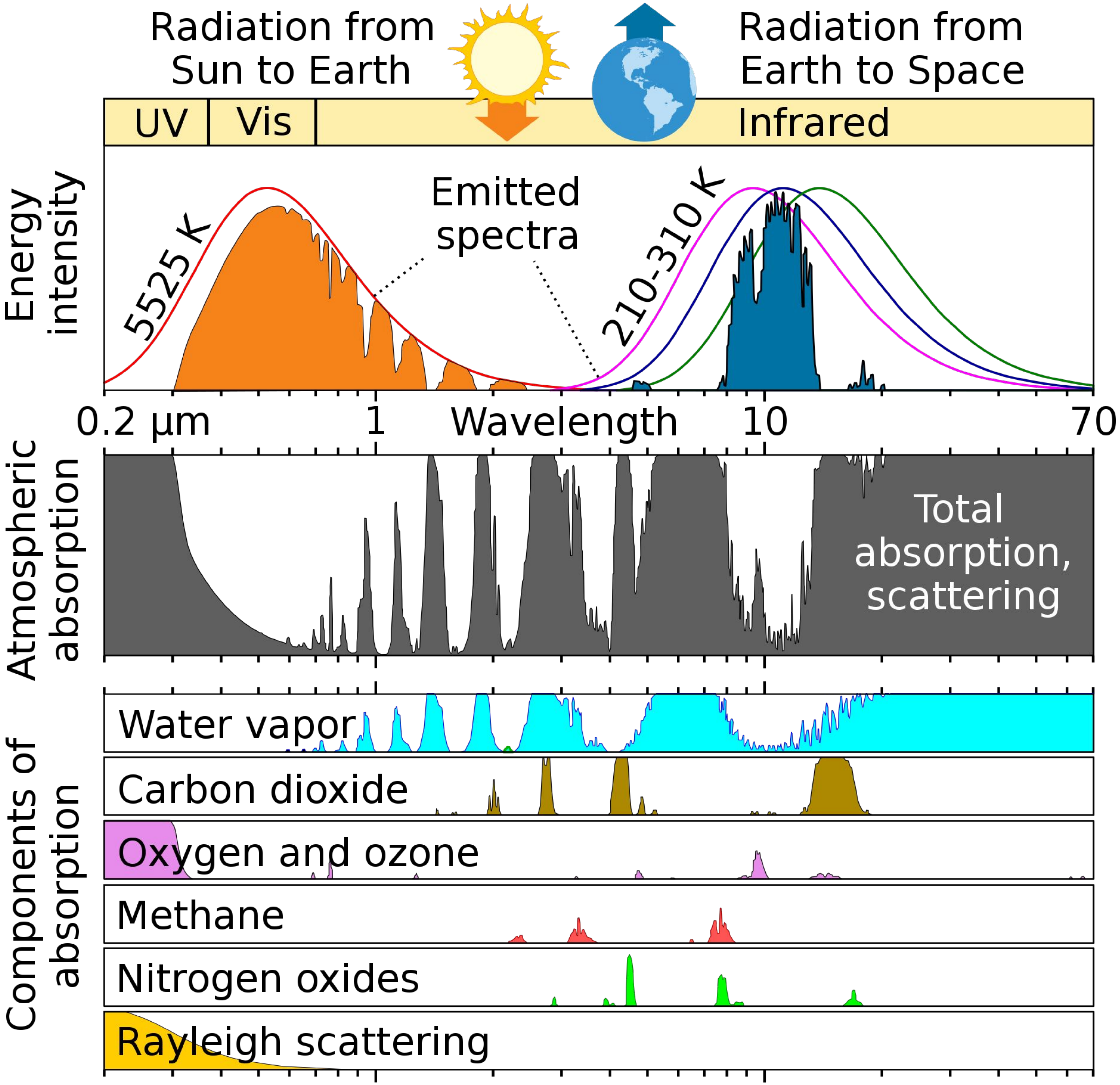
radconstants

```
! Solar irradiance at 1 A.U. in W/m^2 assumed by radiation code
! Rescaled so that sum is precisely 1368.22 and fractional amounts sum to 1.0
real(r8), parameter :: solar_ref_band_irradiance(nswbands) = &
   (/                                        &
      12.11_r8,  20.3600000000001_r8, 23.73_r8,           &
      22.43_r8,  55.63_r8, 102.93_r8, 24.29_r8,           &
      345.74_r8, 218.19_r8, 347.20_r8,                    &
      129.49_r8,  50.15_r8,   3.08_r8, 12.89_r8           &
   /)
```

rad_solar_var

```
if ( do_spctrl_scaling ) then
  call integrate_spectrum( nbins, nradbins, we, radbinmin, radbinmax, sol_irrad, irrad)
  sfac(:nradbins) = irrad(:nradbins)/ref_band_irrad(:nradbins)
else
   sfac(:nradbins) = sol_tsi/tsi_ref
endif
```

$CAM/src/chemistry/utils/solar_irrad_data
sol_tsi is module data
Initialized by call to solar_irrad_init from radiation_init
that (basically) calls get_ref_total_solar_irrad in radconstants, and that is only
tsi = sum(solar_ref_band_irradiance)
where solar_ref_band_irradiance



https://en.wikipedia.org/wiki/Atm