CKDMIP progress meeting 8 Sept 2020

1. What is required from participants?
2. Results so far
5. Questions for discussion

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ECMWF

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Any objections to recording this meeting for the benefit of colleagues who could not attend? Recording will not be posted publicly on internet.

Agenda

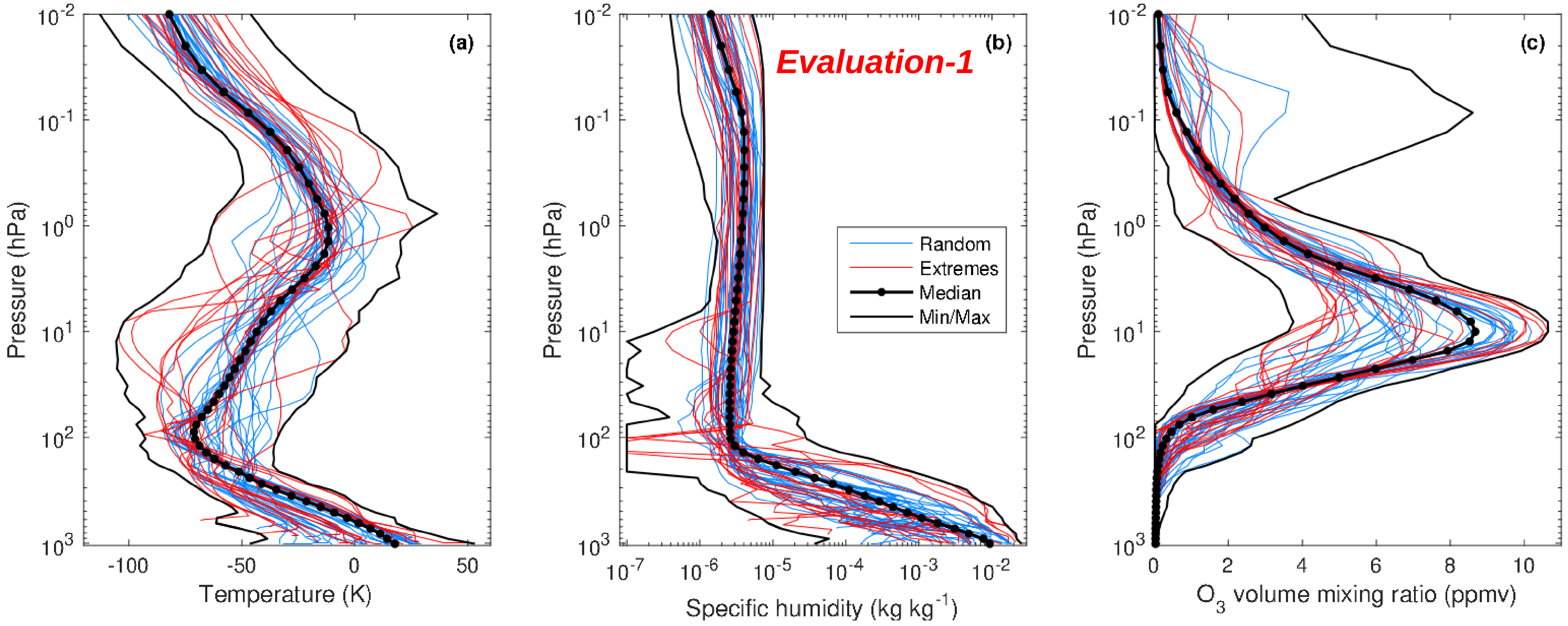
1. What is being asked of CKDMIP participants? (Robin)
   - Discussion: what further help/software/data would be of use to participants?
2. Summary of results so far (Robin)
3. Overview of SOCRATES CKD tool (James Manners)
   - Discussion: what are the interesting differences between CKD approaches that we can evaluate using the CKDMIP dataset?
4. Towards a community tool chain for gas optics (Robert Pincus)
   - Discussion: what are the community needs, can existing codes be released open source?
5. Discussion of next steps (all)
   - What is a realistic timeline: from gathering contributions from all models to a CKDMIP results paper?
   - What else is needed, e.g. clouds, spectrally varying surface albedo, non-LTE…?
   - Next meeting(s)?

Objectives

- To use benchmark line-by-line calculations to evaluate the accuracy of existing CKD models. *Done for RRTMG, RRTMGP and RRTMGP-NN (LW)*
- To explore how accuracy varies with number of k-terms / g-points in individual CKD schemes for applications spanning short-range weather forecasting to climate modelling. *Done for ecCKD*
- To understand how different choices in way that CKD models are generated affects their accuracy for the same number of g-points.
- To provide freely available datasets and software to facilitate the development of new gas-optics models, with the ultimate aim of producing a community tool to allow users to generate their own gas-optics models targeted at specific applications.

100 evaluation profiles of *T*, *q* and [O_3] in two evaluation datasets

- *Evaluation-1:* 50 profiles for which the LBL spectra and broadband fluxes are available to participants
- *Evaluation-2:* 50 profiles for which the spectra and fluxes are withheld for independent evaluation



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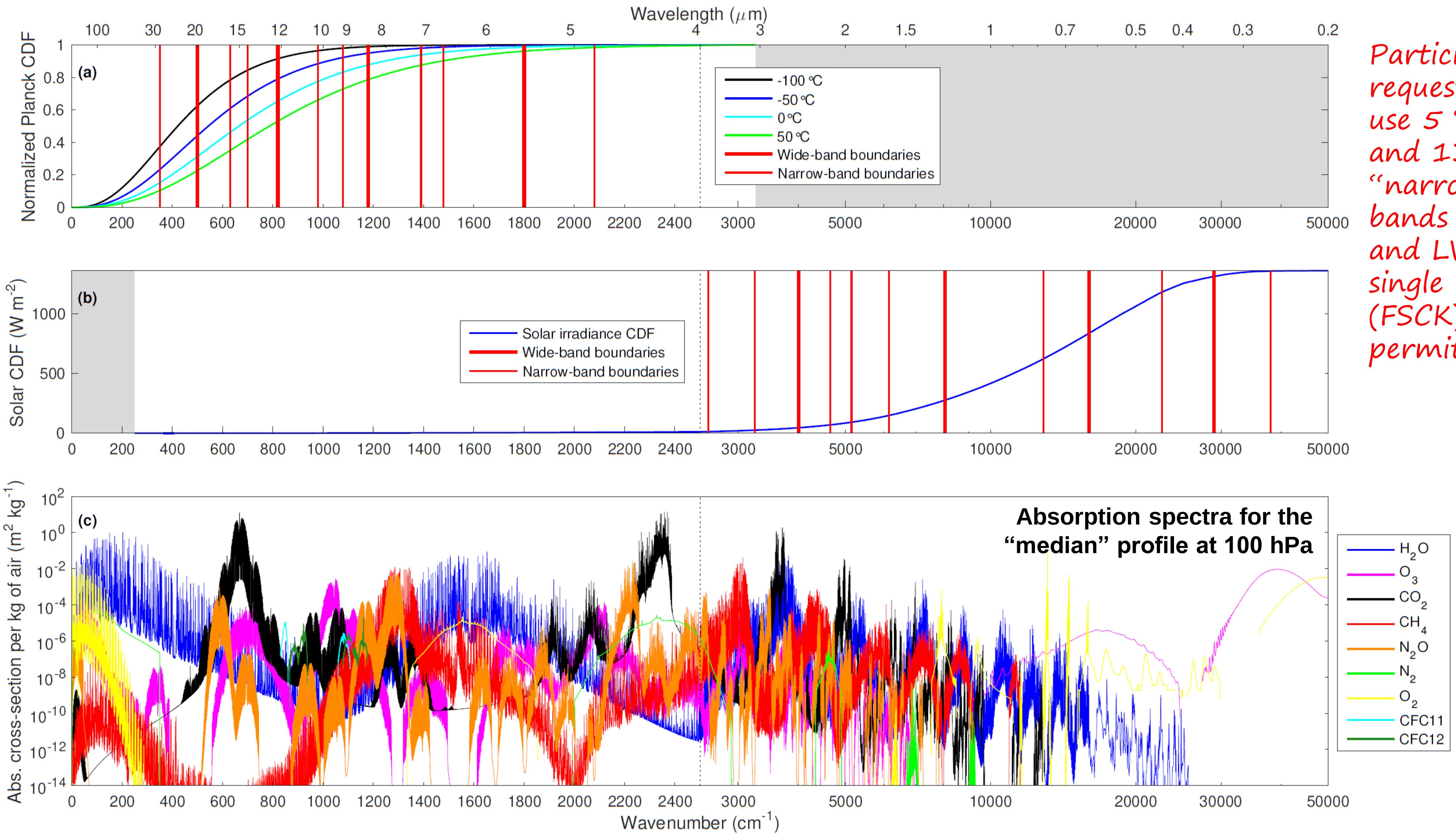
Trace gas variations: 34 scenarios (18 in shortwave)

justification

Scenario	Comment	CO_2 ppmv	CH_4 ppbv	N_2O ppbv	CFC-11 eq. pptv	CFC-12 pptv
1	Glacial maximum	**180**	**350**	**190**	**32**	**0**
2	Preindustrial	**280**	**700**	**270**	**32**	**0**
3	Present-day (2020)	415	1921	332	861	495
4	Future (2110)	**1120**	**3500**	**405**	**2000**	**200**
5–9	CO_2 forcing	**180, 280, 560, 1120, 2240**	1921	332	861	495
10–14	CH_2 forcing	415	**350, 700, 1200, 2600, 3500**	332	861	495
15–18	N_2O forcing	415	1921	**190, 270, 405, 540**	861	495
*19–20	CFC-11 forcing	415	1921	332	**0, 2000**	495
*21–22	CFC-12 forcing	415	1921	332	861	**0, 550**
*23–24	CO_2/CH_4 overlap	**180, 2240**	**350**	332	861	495
*25–26		**180, 2240**	**3500**	332	861	495
*27–28	CO_2/N_2O overlap	**180, 2240**	1921	**190**	861	495
*29–30		**180, 2240**	1921	**540**	861	495
*31–32	CH_4/N_2O overlap	415	**350, 3500**	**190**	861	495
*33–34		415	**350, 3500**	**540**	861	495

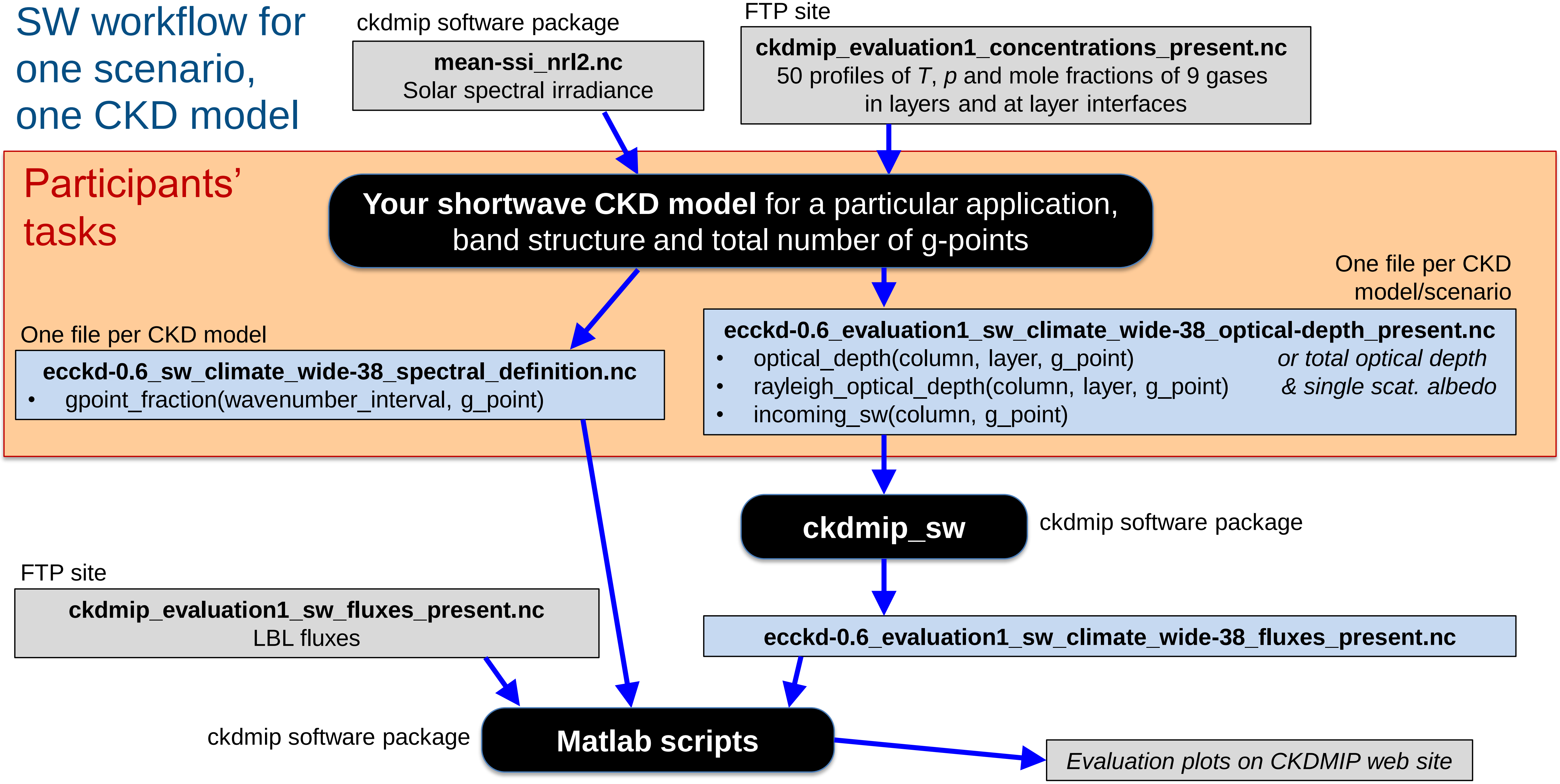
- One concentration file per scenario, containing 50 profiles
- 2x50x34 = 3400 profiles in 2x34 = 68 files, e.g. **ckdmip_evaluation1_concentrations_present.nc**



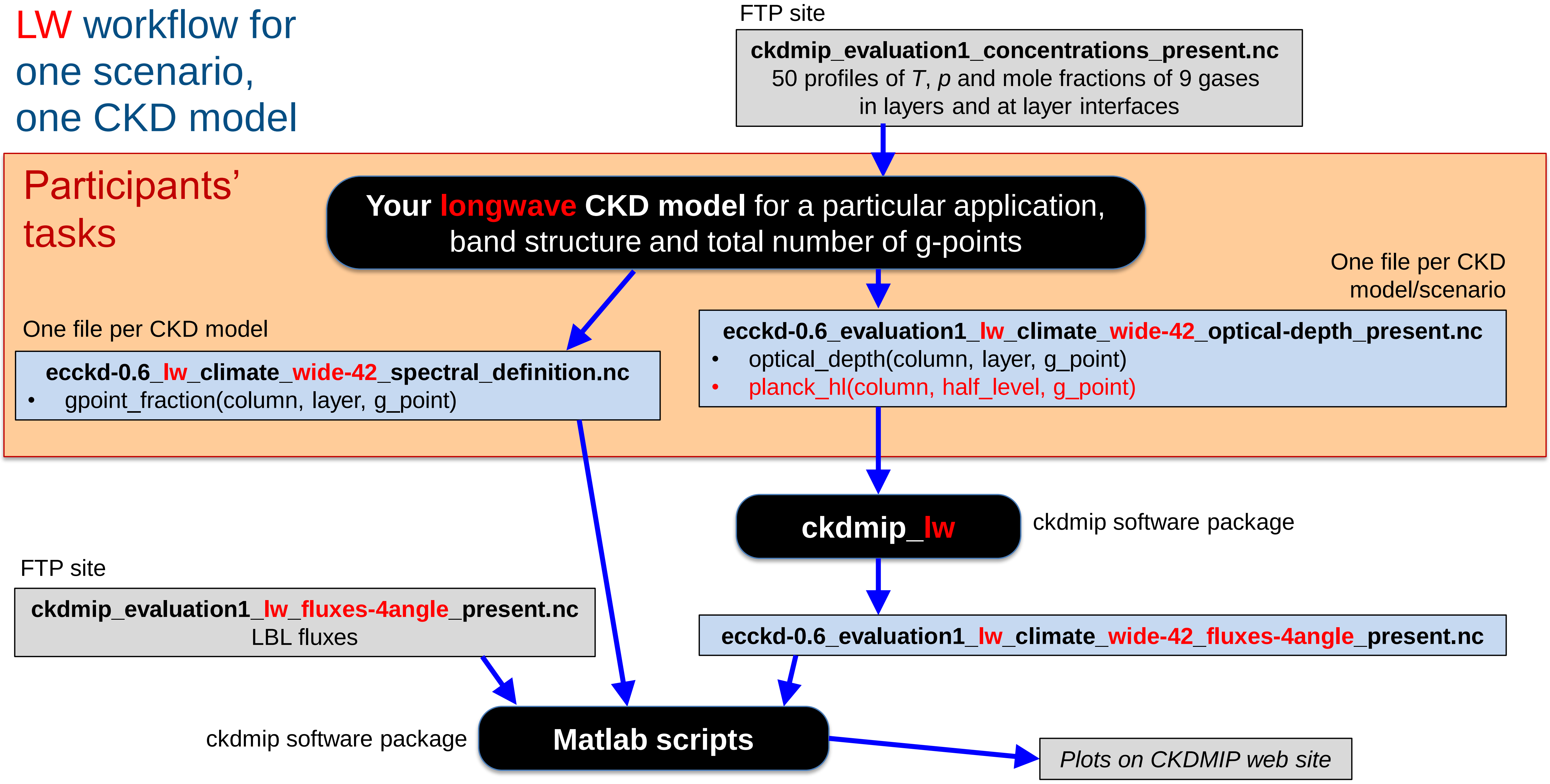
Participants requested to use 5 "wide" and 13 "narrow" bands in SW and LW, but single band (FSCK) also permitted

Line-by-line absorptions calculated by Marco Matricardi

SW workflow for one scenario, one CKD model



LW workflow for one scenario, one CKD model



How many CKD models should I submit?

- Can be as few as one, e.g. RRTMG, RRTMGP, Fu-Liou…
- If it affects the number of g points you need, you can vary the *application*:
  - Climate (all scenarios, 0.02-1100 hPa), Global NWP (present-day scenario only, 0.02-1100 hPa), Limited-area NWP (present-day scenario, 4-1100 hPa)
  - Evaluation statistics will be limited to applicable scenarios and pressure ranges
- You can vary the *band structure:*
  - CKDMIP proposes a set of *narrow* and *wide* bands, but other band structures accepted
- You can vary the number of *g points (k terms)*
  - Explore the trade-off between accuracy and efficiency
- Could be 3x2x6 = 36 different CKD models! Up to you how many you submit depending on interest (e.g. only climate) and your time

What do I do with the LBL datasets?

- If you can only use your own LBL model to generate CKD models, you can ignore them
- However, intention of CKDMIP is to compare CKD models generating assuming the *same* spectroscopy, so we can eliminate spectroscopy differences as a cause of apparent errors
- Therefore, the FTP site contains absorption spectra for three of the four CKDMIP datasets (*Evaluation-2* held back for independent evaluation) using LBLRTM 12.8, which you can use for training (ecCKD uses all three of these datasets, for example)

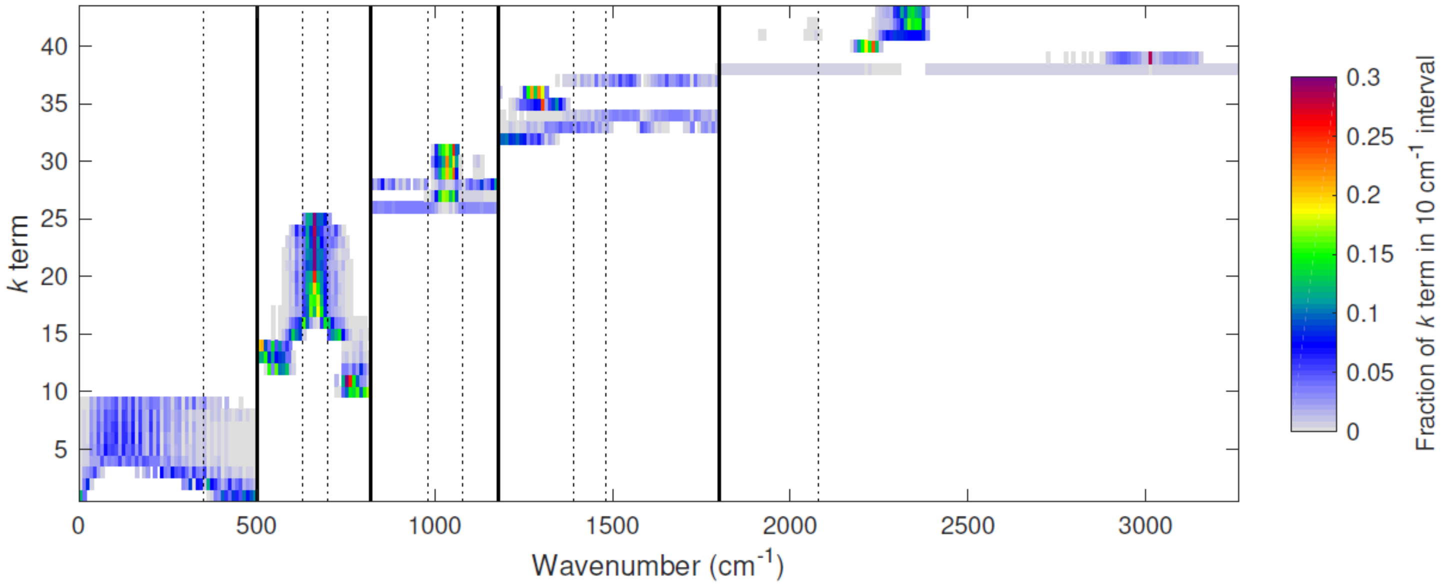
Name	Purpose	Layers	T profiles	Description
Evaluation-1	Training & evaluation	54	50	Realistic profiles selected from NWP-SAF dataset
Evaluation-2	Independent evaluation	54	50	Further profiles selected from NWP-SAF dataset
MMM	Training	52	3	Median, min. and max. of NWP-SAF T, q and O_3 profiles
Idealized	Generating look-up tables	53	11	Idealized profiles regularly spaced in T, $\log p$ and $\log q$

- The Technical Guide explains how the CKDMIP software can be used to perform some manipulation of these datasets, including radiative transfer calculations
- See [contents of FTP site]

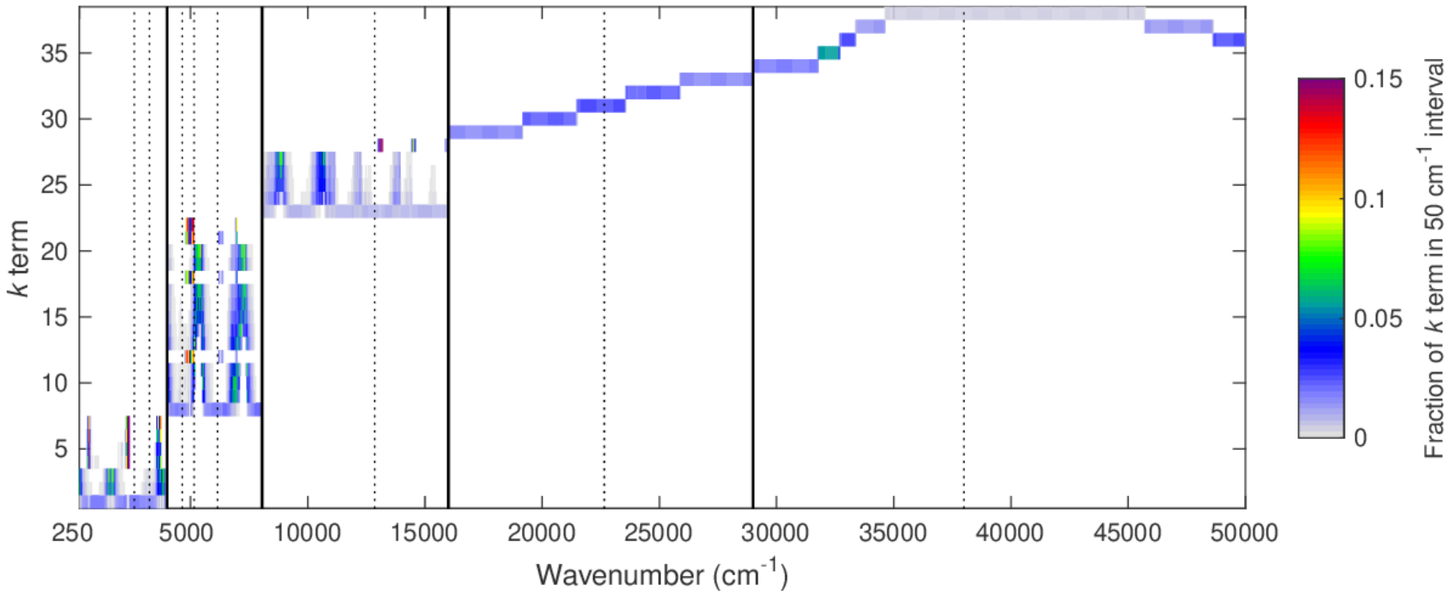
What does the “spectral definition” file contain?

- Normally we have *N* g-points in a band but don’t care *where* in the band
- For wide bands this becomes important when representing clouds: for more accuracy the cloud optical properties could be parameterized per g point not per band
- The spectral definition file contains gpoint_fraction, which sums to 1 along the wavenumber axis
- If your model uses a different g(wn) relationship at different pressures, I suggest you use a mid-tropospheric reference pressure of 500 hPa
- If difficult, I can generate a “dummy” file…
- Jump to end

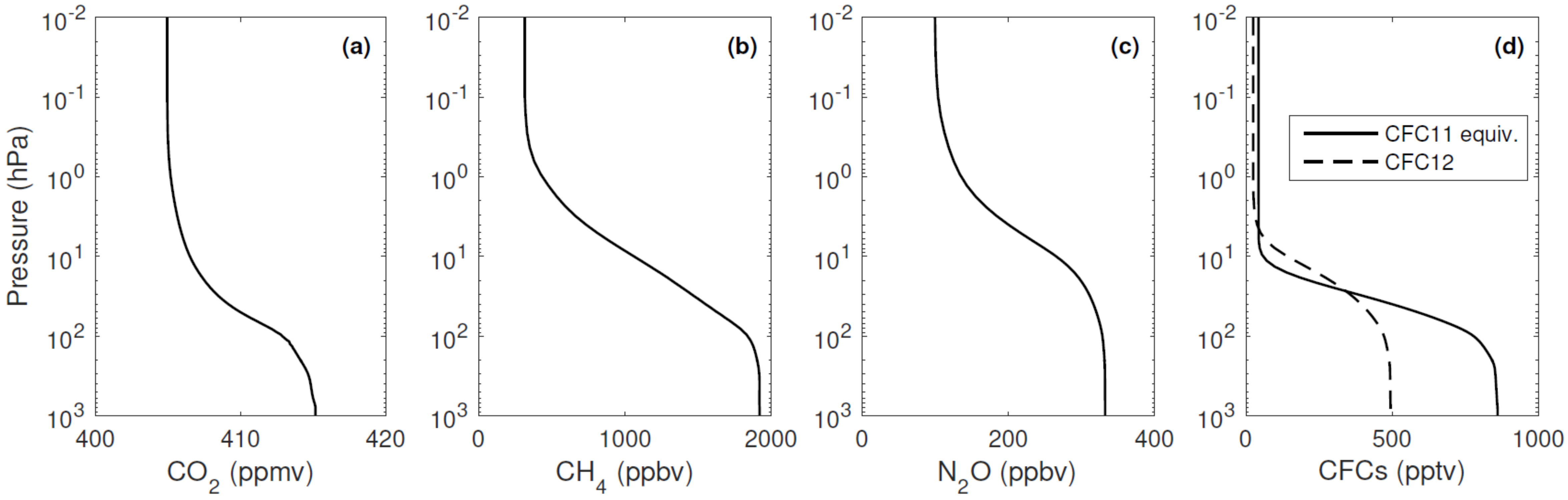
Longwave ecCKD wide-43 model



Shortwave ecCKD wide-38 model



Use realistic vertical profiles for the five well-mixed greenhouse gases



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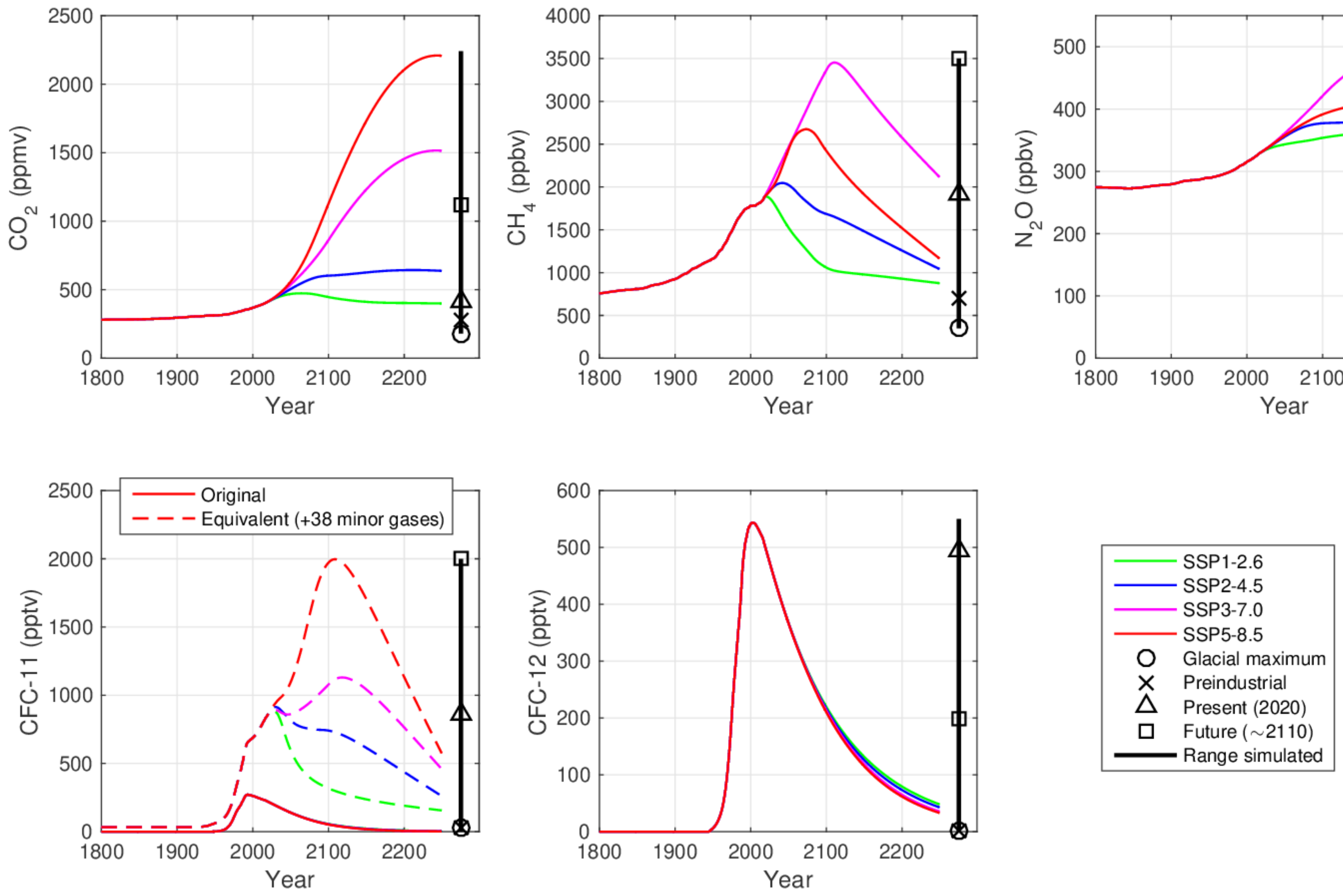
CKDMIP *Evaluation-1* dataset: Well-mixed gases



- Consider five well-mixed greenhouse gases
- Further 38 implicitly considered via "equivalent CFC11" (Meinshausen et al. 2017)
- Evaluate concentrations from Glacial Maximum to the worst of the CMIP6 future scenarios
- Participants produce CKD models for both climate and present-day NWP
- Per-molecule absorption of these gases is independent of concentration, so only store absorption spectra at one concentration and scale
- Also N_2 and O_2 absorption

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Three “applications”

Application	Lowest pressure	GHG concentrations
Limited-area NWP	4 hPa	Present-day (2020)
Global NWP	0.02 hPa	Present-day (2020)
Climate	0.02 hPa	Variable

- Most contributors are interested primarily in the “climate” application: your model will be tested over all 34 climate scenarios at pressures down to 0.02 hPa
- If you think you can produce a faster CKD model (fewer g points) for present-day NWP applications, you can submit results for separate CKD models that will be evaluated only using the “present” greenhouse-gas scenario, and optionally also only pressures down to 4 hPa for limited-area NWP

Two proposed band structures: 13 narrow bands, 5 wide bands

Longwave

Narrow bands			Wide bands	
#	Spectral interval (cm^{-1})	RRTMG k terms	#	Label
1	0–350	8	1	Far infrared
2	350–500	14		
3	500–630	16	2	Main CO_2 band
4	630–700	14		
5	700–820	16		
6	820–980	8	3	Infrared window
7	980–1080	12		
8	1080–1180	8		
9	1180–1390	12	4	Mid-infrared A
10	1390–1480	6		
11	1480–1800	8		
12	1800–2080	8	5	Mid-infrared B
13	2080–3260	10		

Shortwave

Narrow bands			Wide bands	
#	Spectral interval (cm^{-1})	RRTMG k terms	#	Label
1	250–2600	12	1	Mid-infrared
2	2600–3250	6		
3	3250–4000	12		
4	4000–4650	8	2	Shortwave infrared
5	4650–5150	8		
6	5150–6150	10		
7	6150–8050	12		
8	8050–12850	10	3	Near infrared
9	12850–16000	8		
10	16000–22650	6	4	Visible window
11	22650–29000	6		
12	29000–38000	8	5	Ultraviolet
13	38000–50000	6		

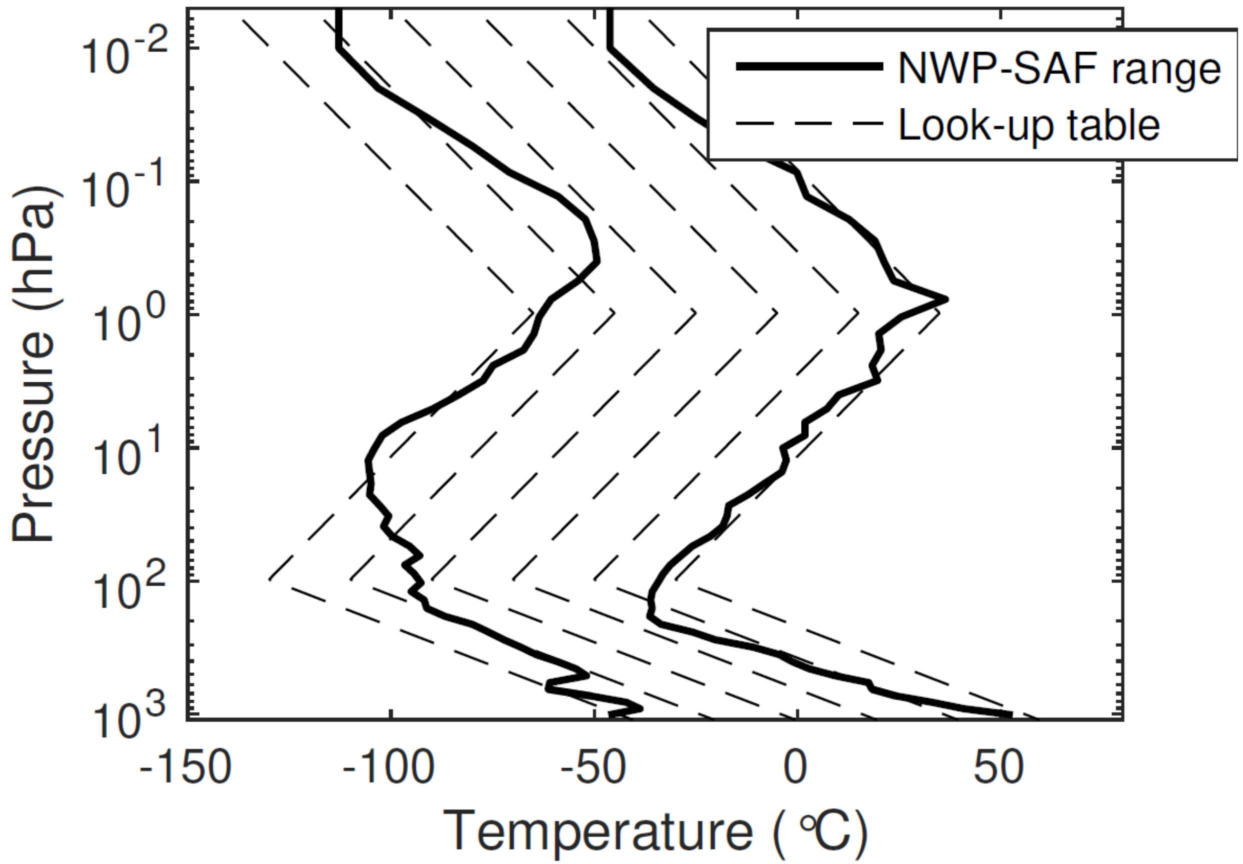
FTP site directory contents

- **concentrations/** 34 scenarios for each of the Evaluation-1 and Evaluation-2 datasets
- **lw_spectral/, sw_spectral/** LBL gas absorption spectra (big!)
  - **evaluation1/** Spectra for *Evaluation-1* dataset (*Evaluation-2* kept back for independent evaluation)
  - **idealized/** Spectra for regularly spaced temperature pressure and humidity – can use for training
  - **mmm/** Spectra for maximum, minimum and median T, q and [O3] – can use for training

  Not essential! Available for participants if they wish
- **lw_fluxes/, sw_fluxes/**: LBL fluxes per narrow band for each scenario & profile – for evaluation
  - **evaluation1/**
- **results/**
  - ***CKD-TOOL*/lw_optical-depth/, *CKD-TOOL*/sw_optical-depth/** Files submitted by participants
  - ***CKD-TOOL*/lw_fluxes/, *CKD-TOOL*/sw_fluxes/** Fluxes calculated by from submitted optical depths

Dataset volumes

- Absorption spectra use 7.1M points in longwave, 3.1M in shortwave
- Stored in NetCDF4/HDF5 format with compression
- *Evaluation-1 dataset:*
  - 50 profiles: 265 GB in LW, 136 GB in SW
- *Evaluation-2 dataset:*
  - For independent evaluation (not released)
  - Same size as Evaluation-1
- *MMM dataset:*
  - Median, min and max profiles
  - 3 profiles: 30 GB in LW, 15 GB in SW
- *Idealized dataset:*
  - For creating CKD look-up tables
  - 6 profiles: 139 GB in LW, 74 GB in SW



End of part 1

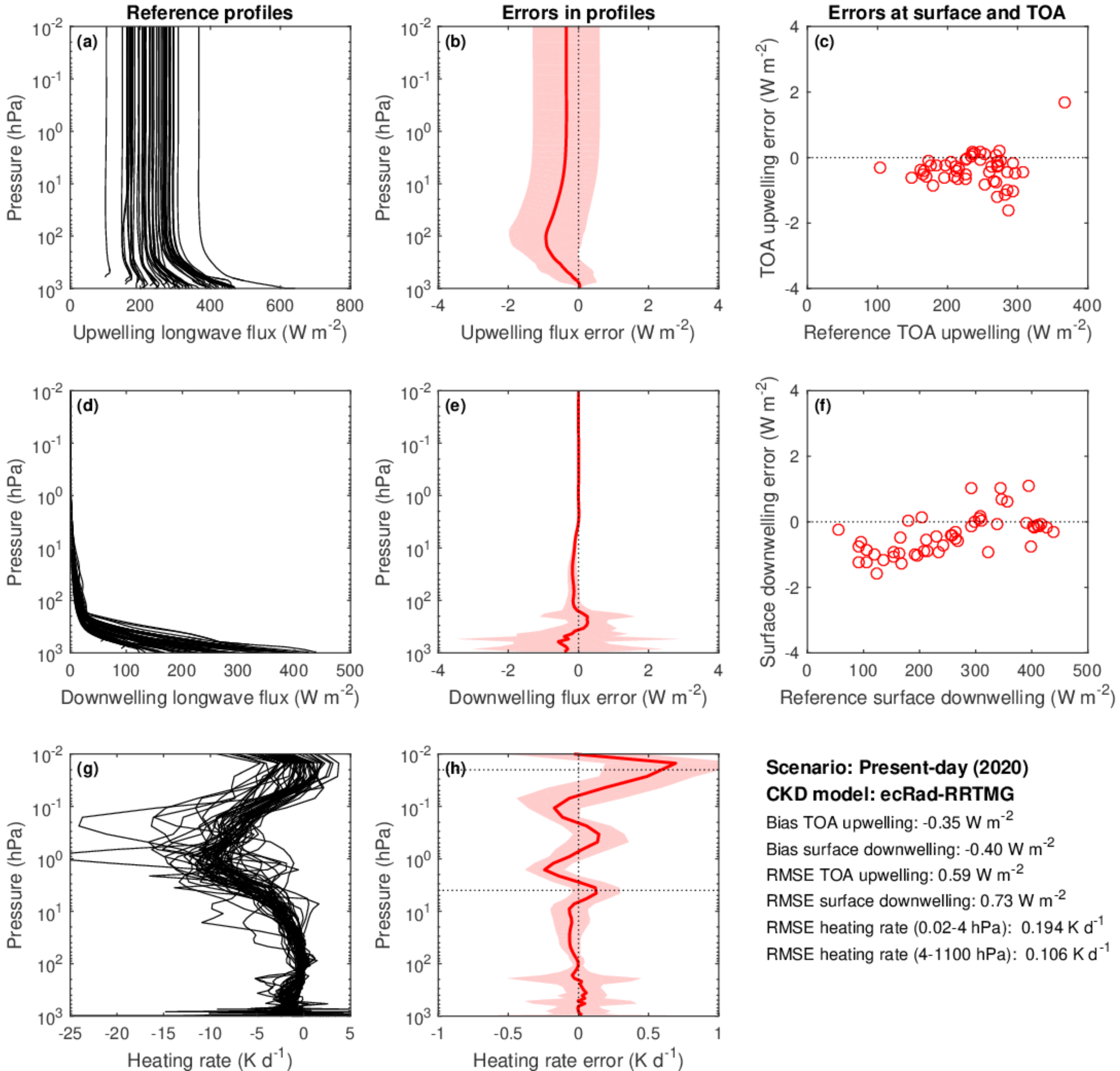
Results Models and tools participating in CKDMIP

CKD model	Contact	LW status	SW status
RRTMG (ecRad)	Robin Hogan	v1.2.0	v1.2.0
RRTMGP (RTE)	Robert Pincus	v181204	v181204
RRTMGP-NN	Peter Ukkonen	v1.0	
MODTRAN	Alexander Berk		
Fu-Liou	Lei Lin		

CKD tool	Contact	LW status	SW status
SOCRATES	James Manners		
ecCKD	Robin Hogan	v0.5	v0.6
ARTDECO-PyKdis	Mathieu Compiegne		
INSA-CNRS/LOA/HYGEOS	Frederic Andre, Mathieu Compiegne		
PSLACKD	Seiji Kato, Fred Rose		
CMA scheme	Hua Zhang		
mstrnX	Miho Sekiguchi		
KBIN	Nils Madenach, Juergen Fischer, Rene Preusker		

Longwave RRTMG

- 16 bands
- 140 g points



Scenario: Present-day (2020)

CKD model: ecRad-RRTMG

Bias TOA upwelling: -0.35 W m^{-2}

Bias surface downwelling: -0.40 W m^{-2}

RMSE TOA upwelling: 0.59 W m^{-2}

RMSE surface downwelling: 0.73 W m^{-2}

RMSE heating rate (0.02-4 hPa): 0.194 K d^{-1}

RMSE heating rate (4-1100 hPa): 0.106 K d^{-1}

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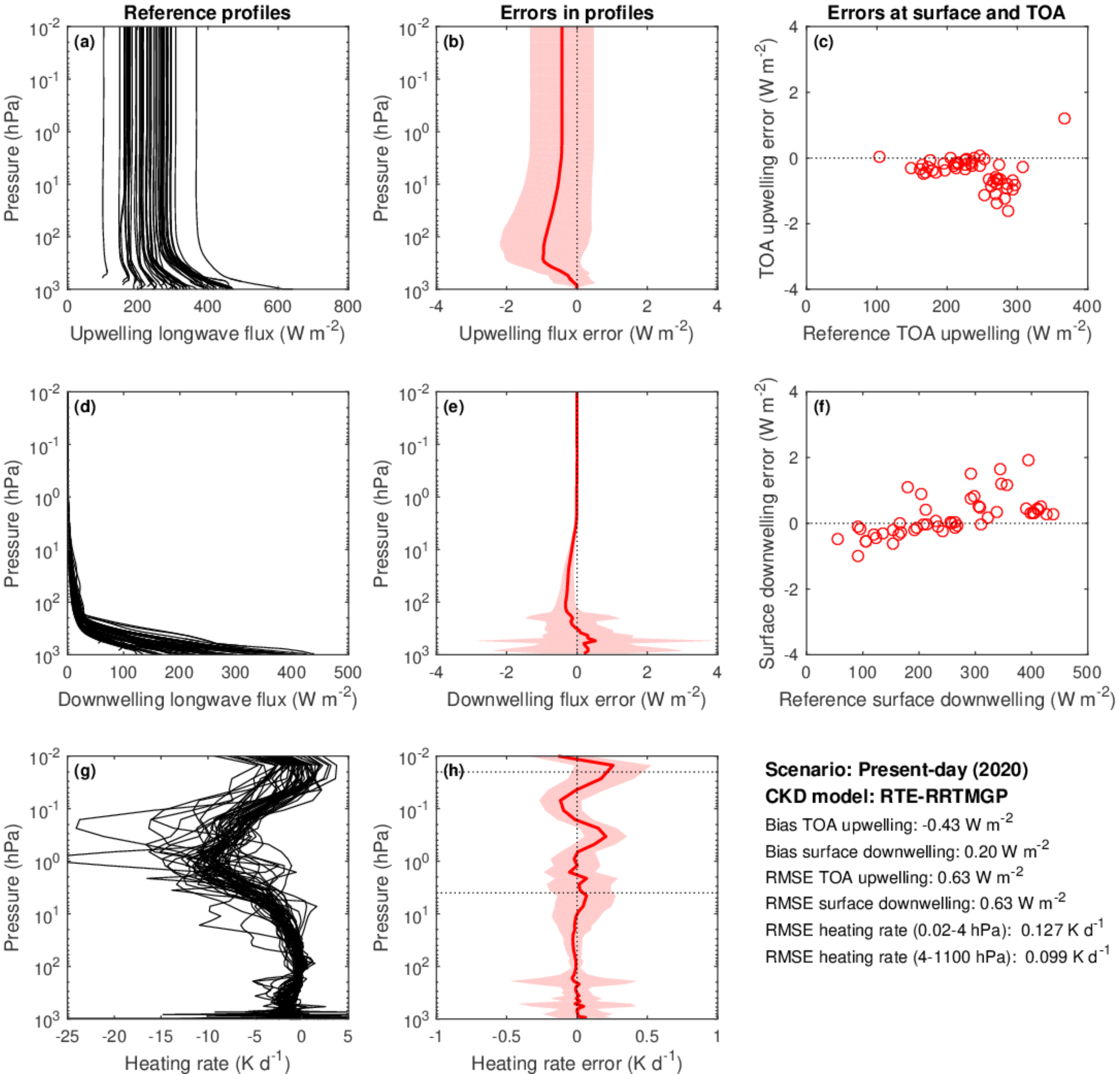
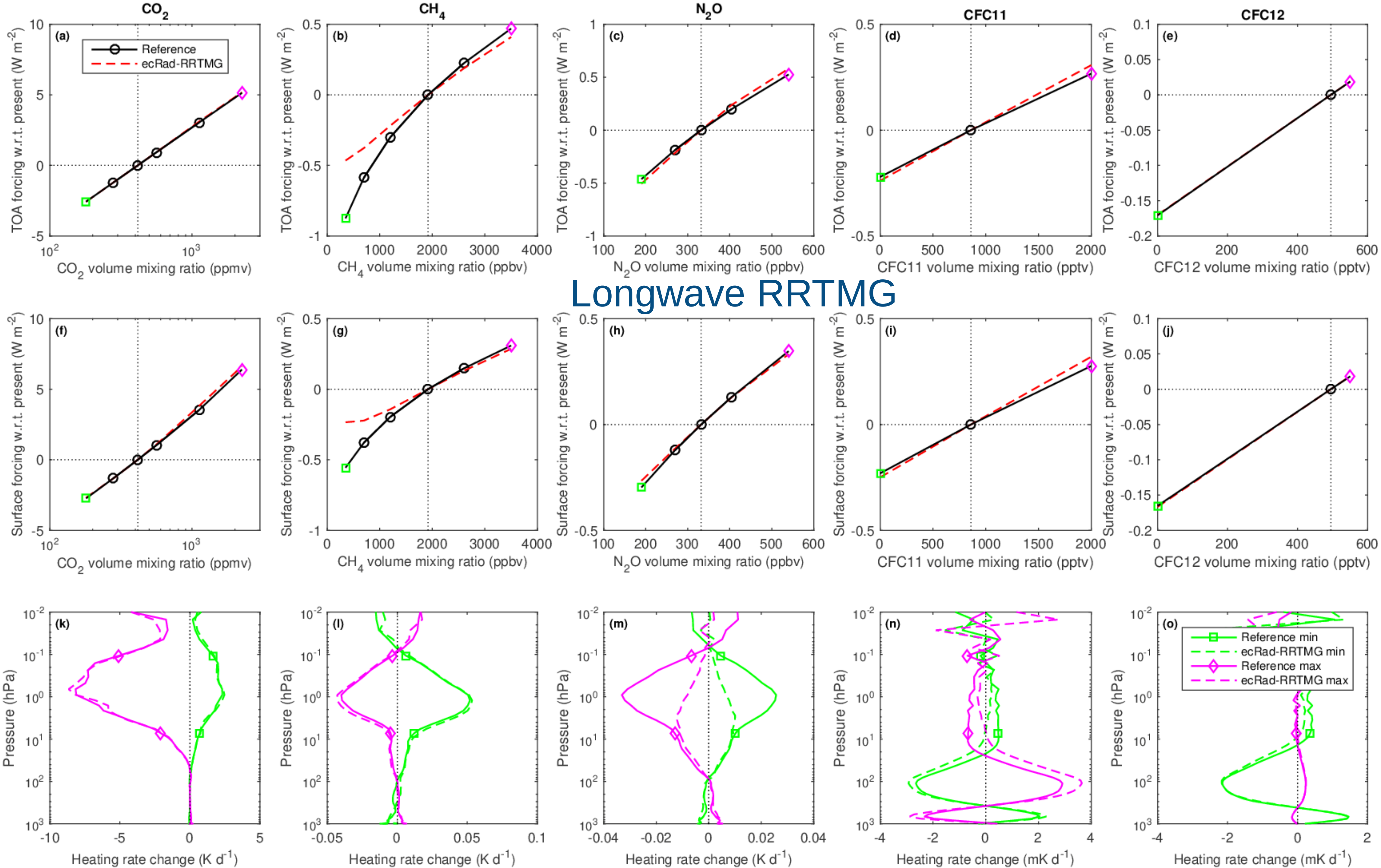
Longwave RRTMGP

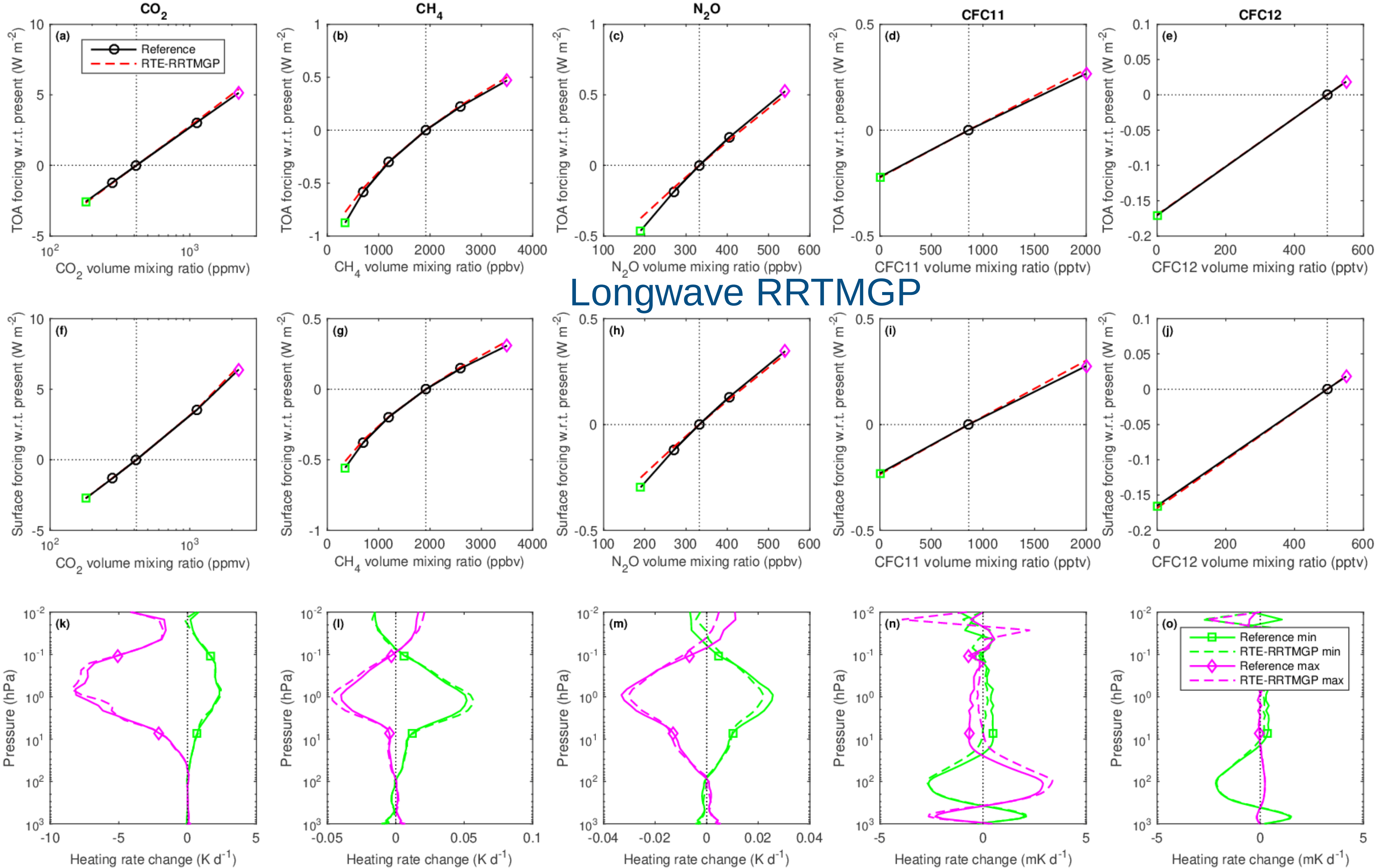
- 16 bands
- 256 g points



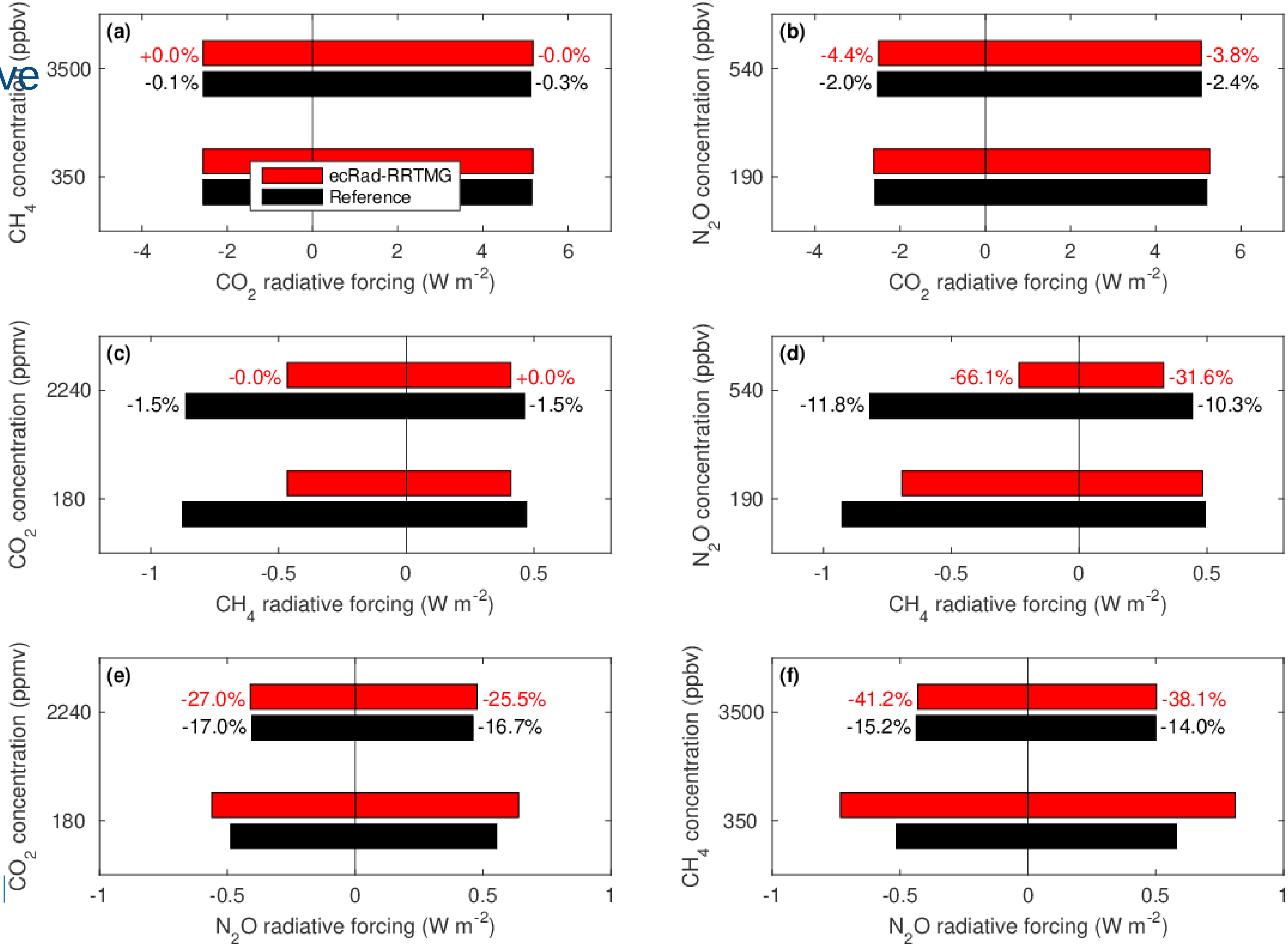
Longwave RRTMG



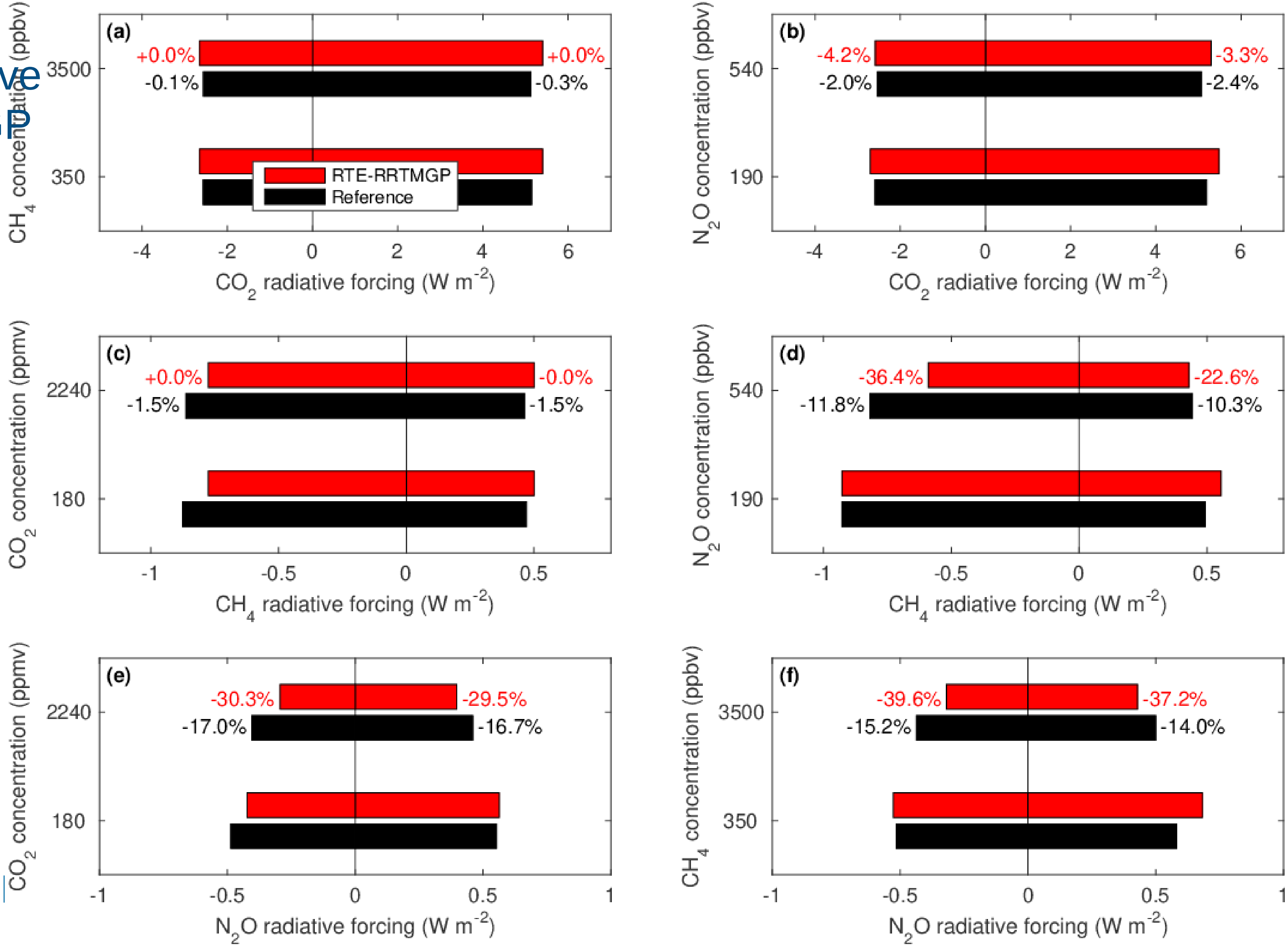
Longwave RRTMGP



Longwave RRTMG

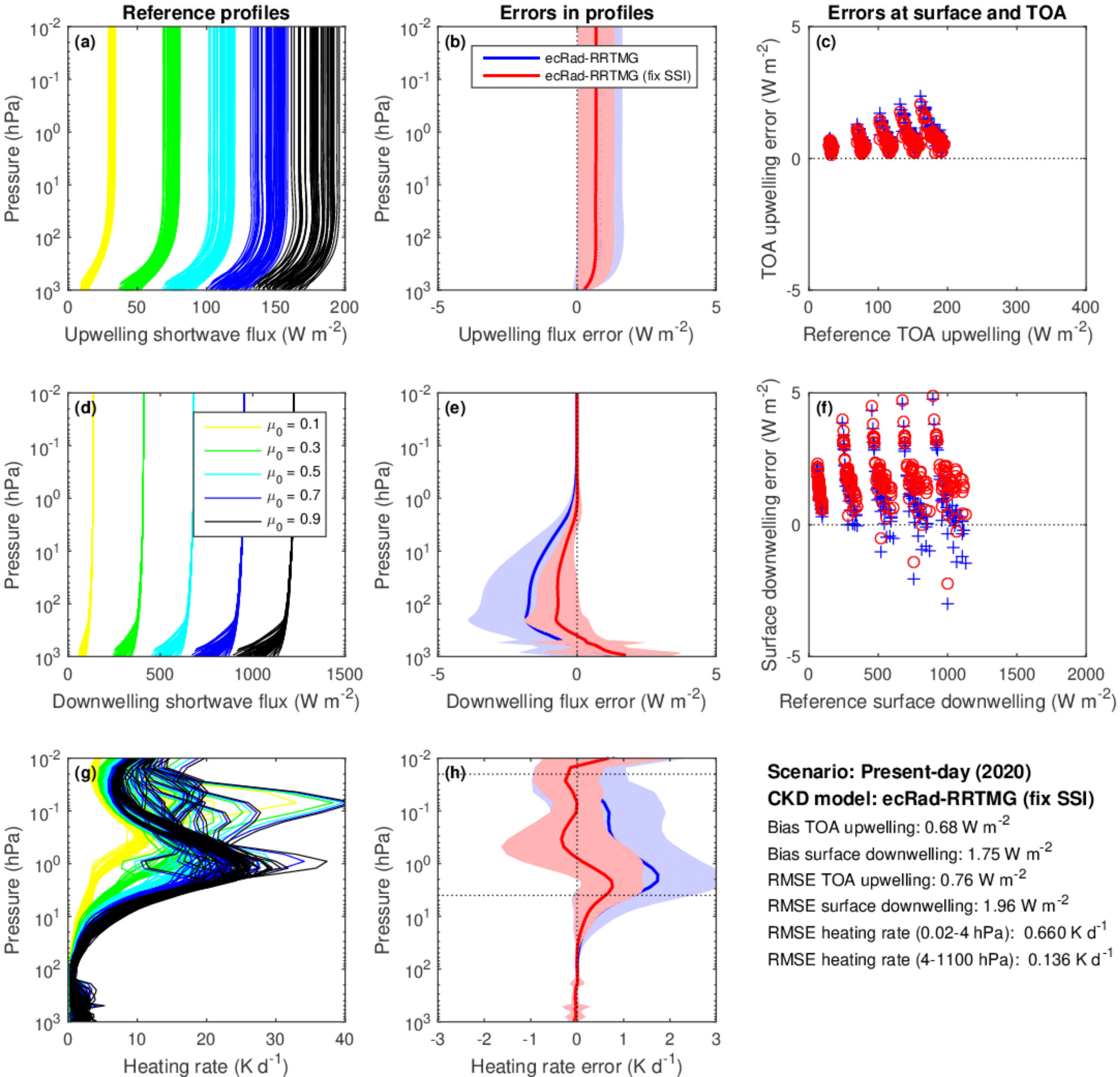


Longwave RRTMGP



Shortwave RRTMG

- 14 bands
- 112 g points



Scenario: Present-day (2020)

CKD model: ecRad-RRTMG (fix SSI)

Bias TOA upwelling: 0.68 W m^{-2}

Bias surface downwelling: 1.75 W m^{-2}

RMSE TOA upwelling: 0.76 W m^{-2}

RMSE surface downwelling: 1.96 W m^{-2}

RMSE heating rate (0.02-4 hPa): 0.660 K d^{-1}

RMSE heating rate (4-1100 hPa): 0.136 K d^{-1}

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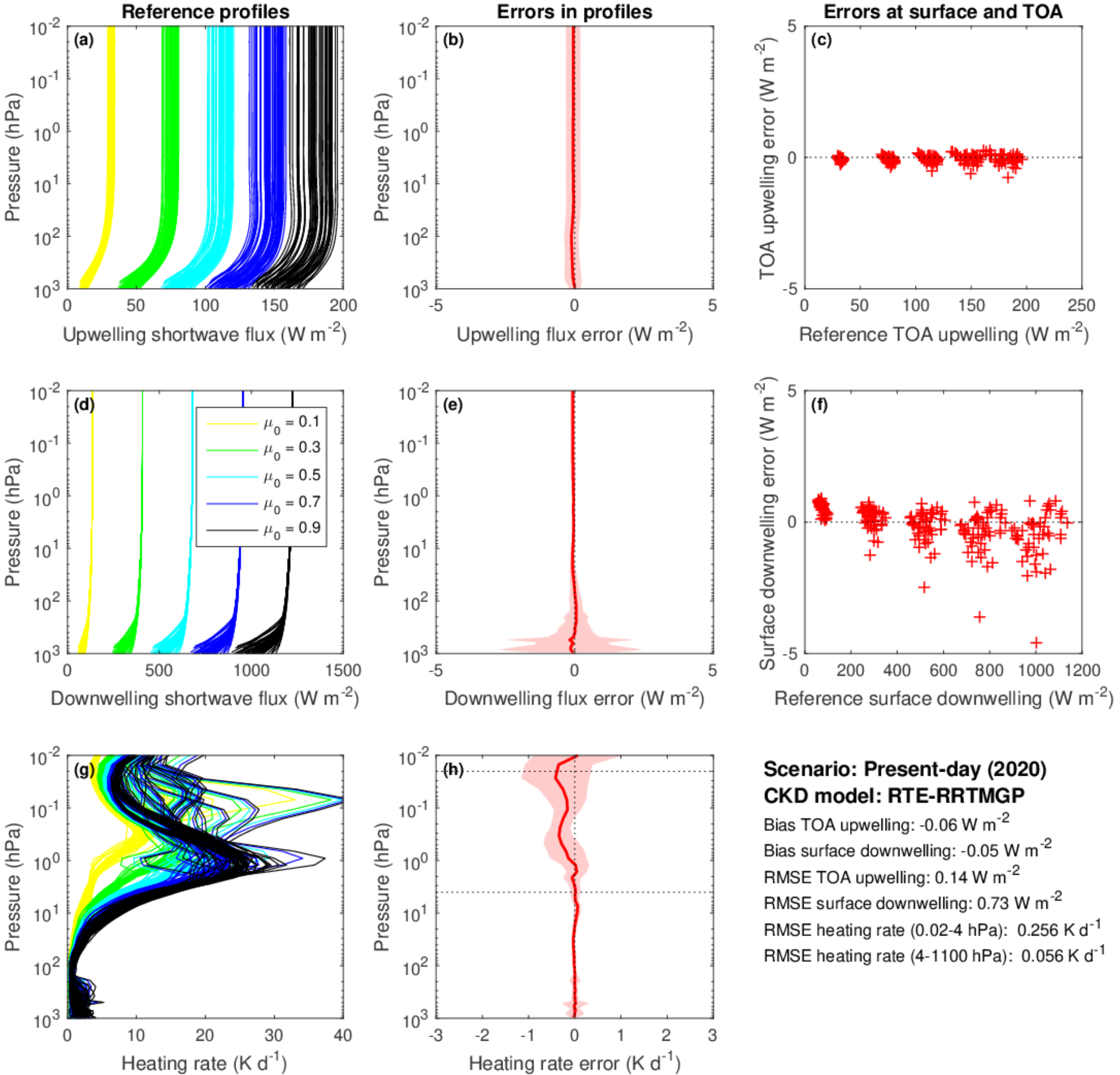
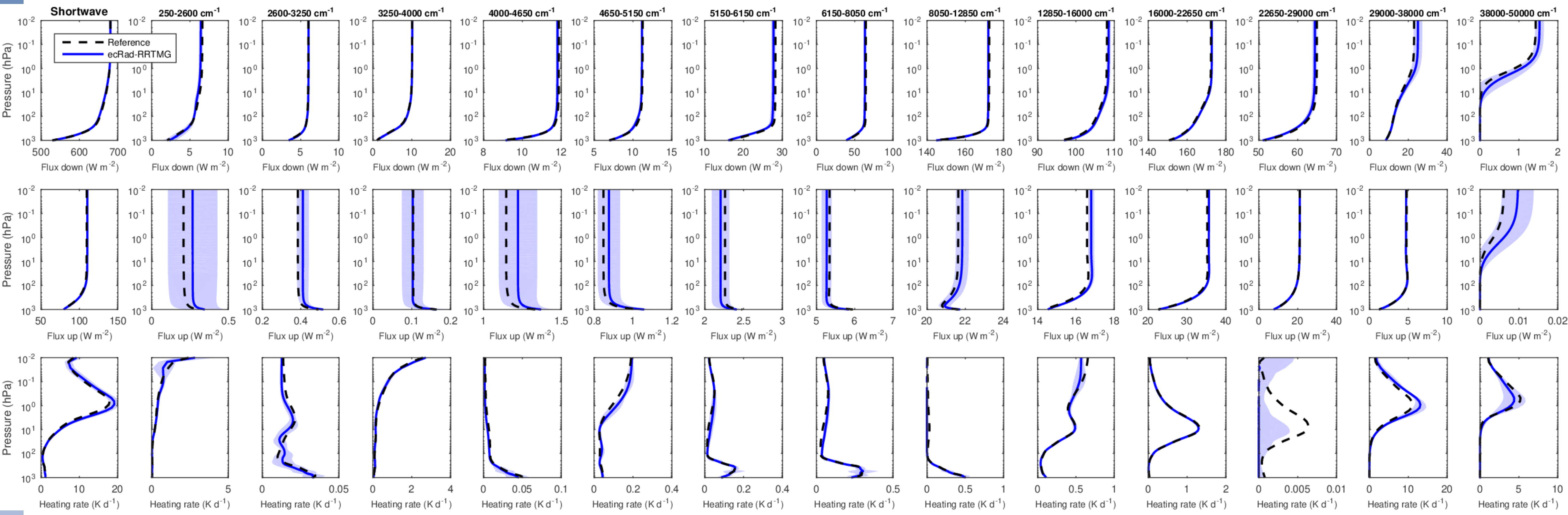
Shortwave RRTMGP

- 14 bands
- 224 g points



ECMWF

Shortwave RRTMG



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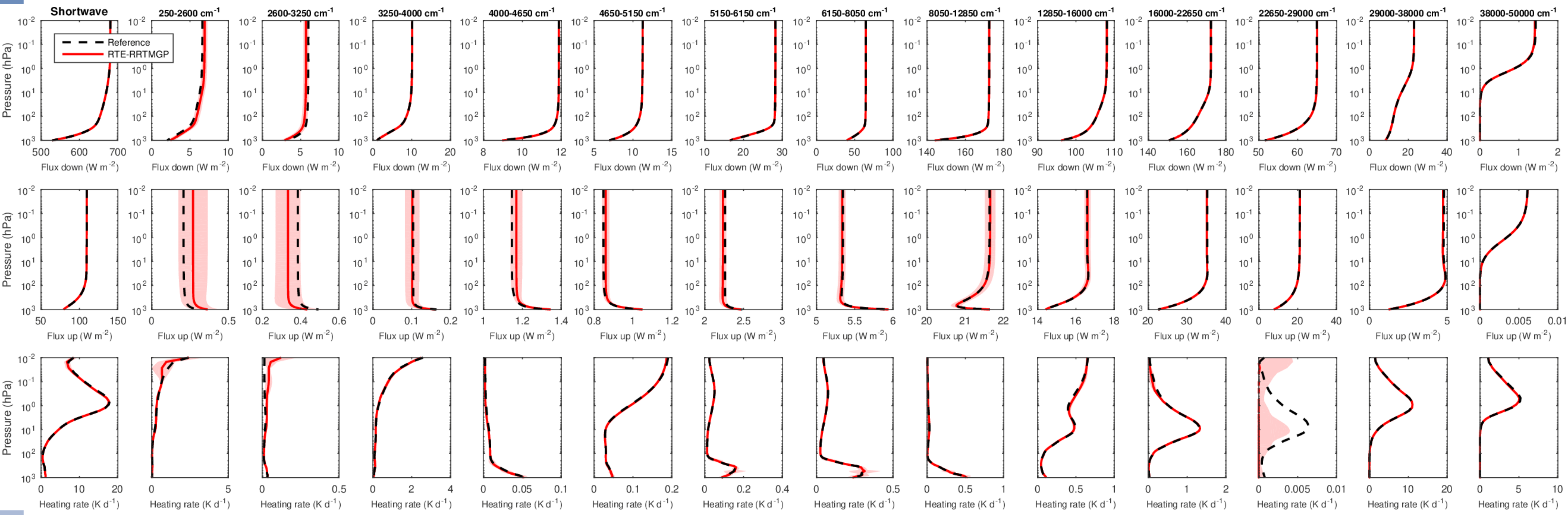
Shortwave RRTMGP



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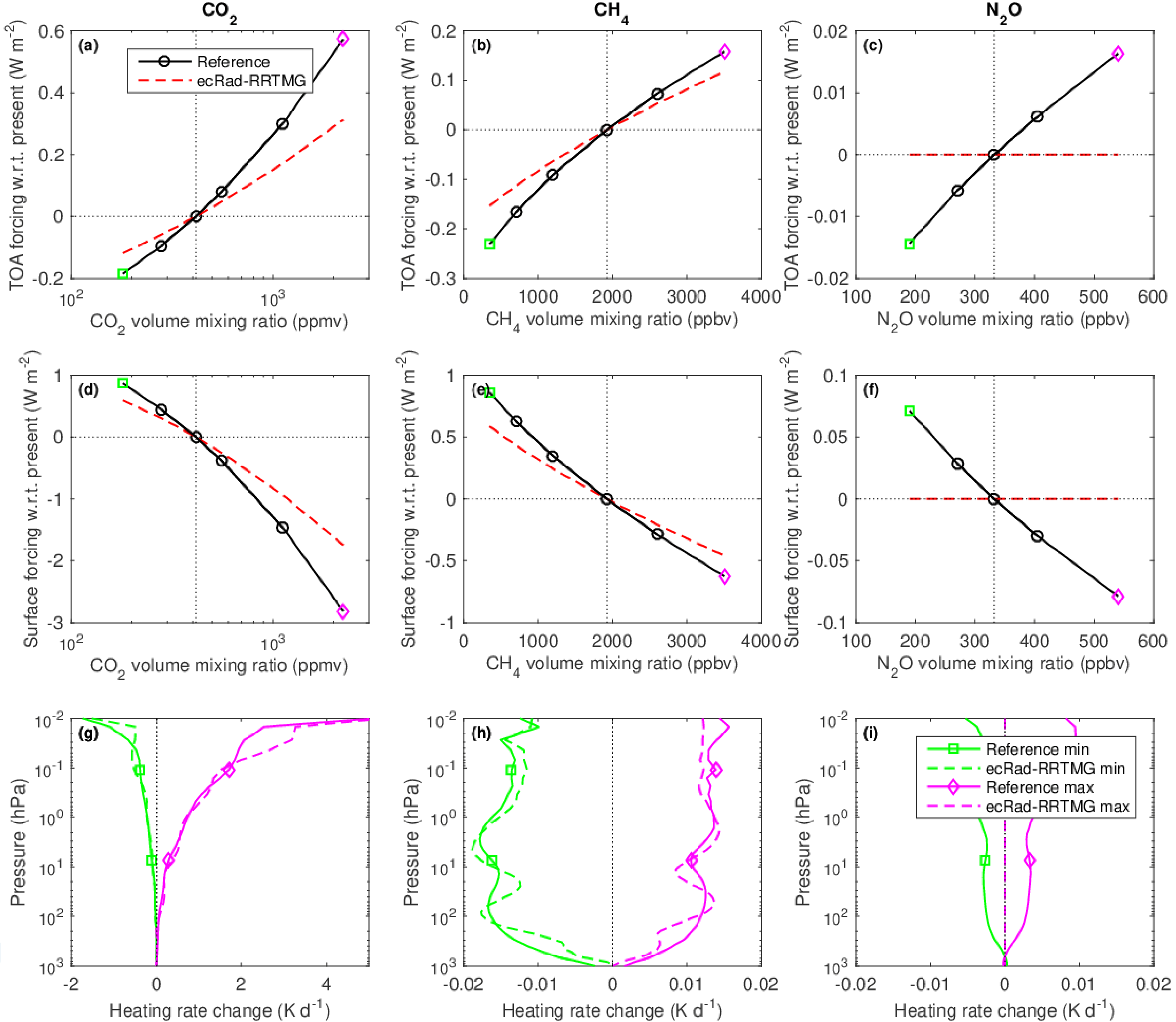
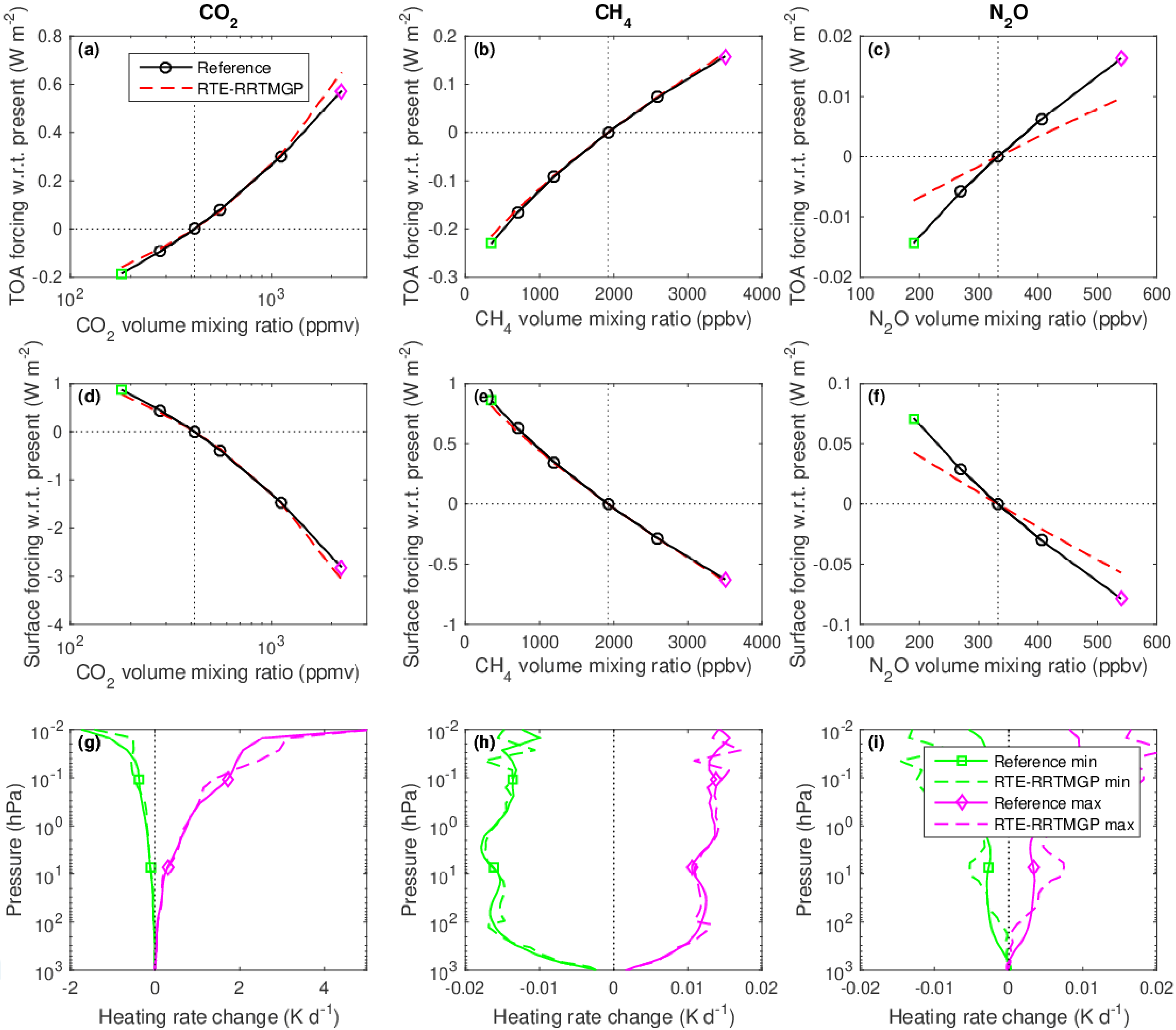
Shortwave RRTMG



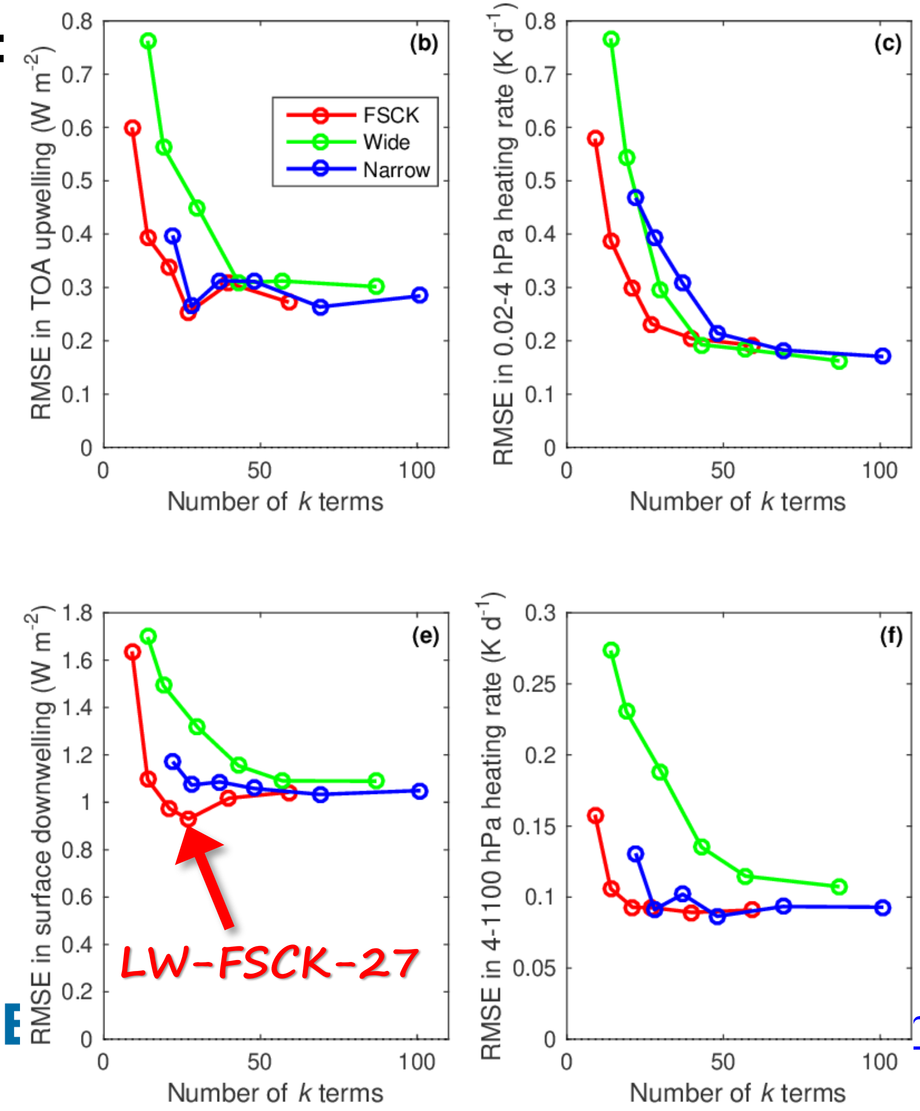
Shortwave RRTMGP



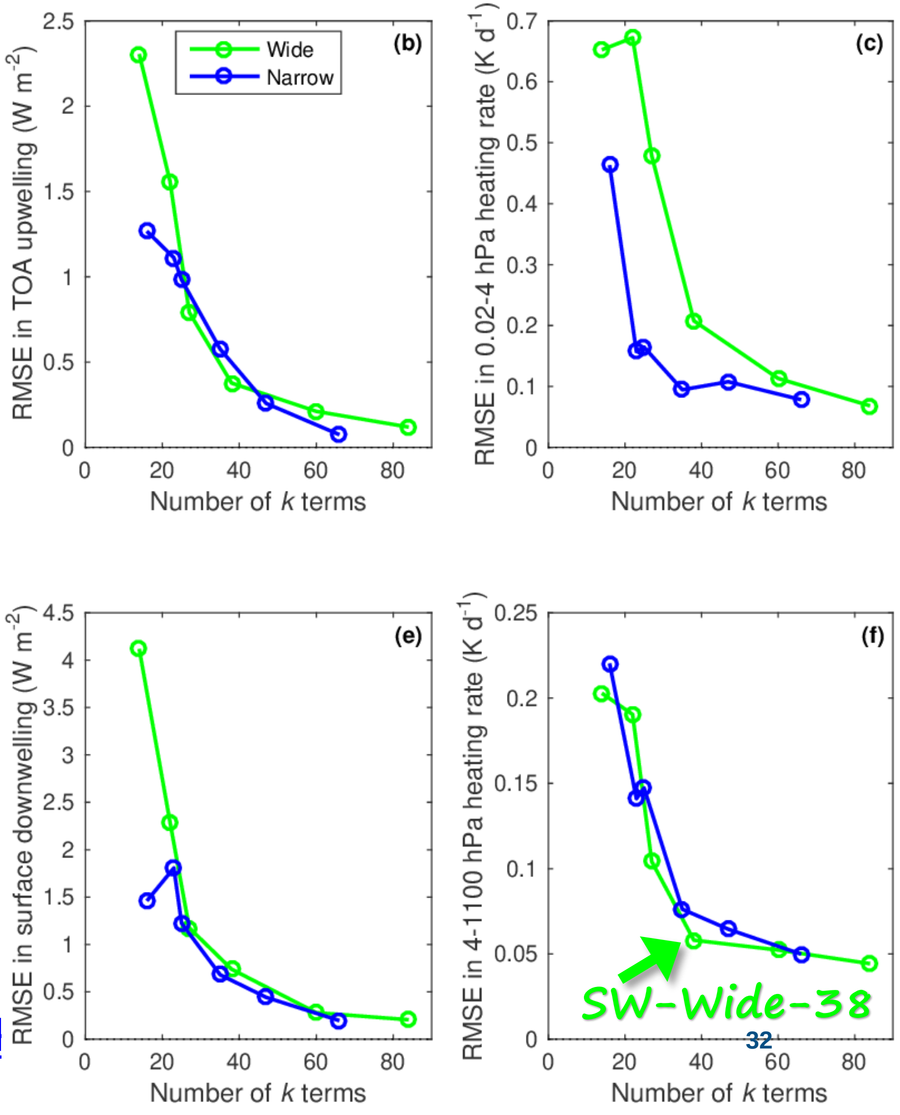
ecCKD: error versus computational cost (number of *k* terms) for all scenarios

- Unsurprisingly, error decreases with number of *k* terms, but can flatten off
- Full-spectrum correlated-k (FSCK) method works well in longwave, but not yet in shortwave

Longwave:



Shortwave:



[See detailed plots]

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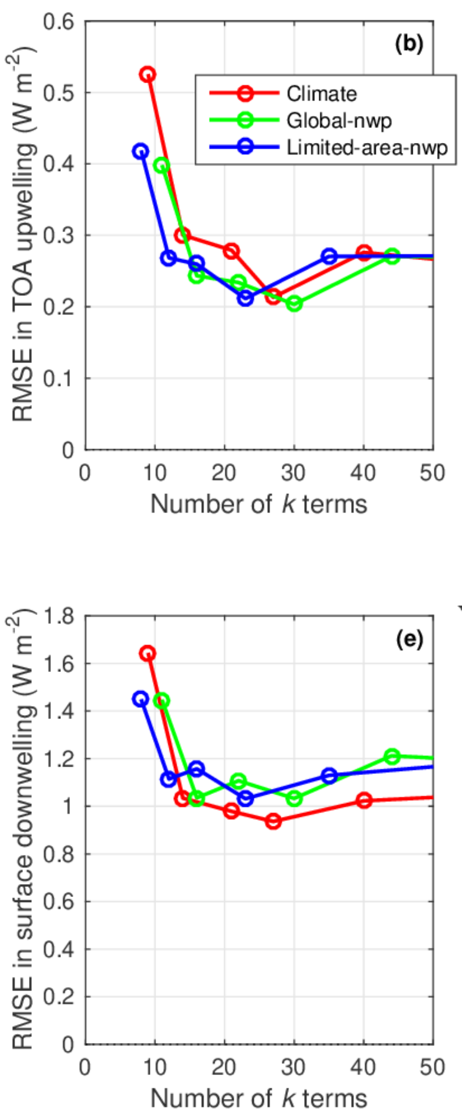
More efficient to train for NWP applications?

- Rather than all climate scenarios, global-nwp trains for present-day only, and low-top limited-area-nwp for pressures larger than 4 hPa (rather than 0.02 hPa)

Longwave:



Shortwave:

Low-top model doesn't waste k terms for accurate heating in upper atmosphere, so gets same accuracy in shortwave fluxes with fewer k terms

Not much difference for global-nwp, or longwave

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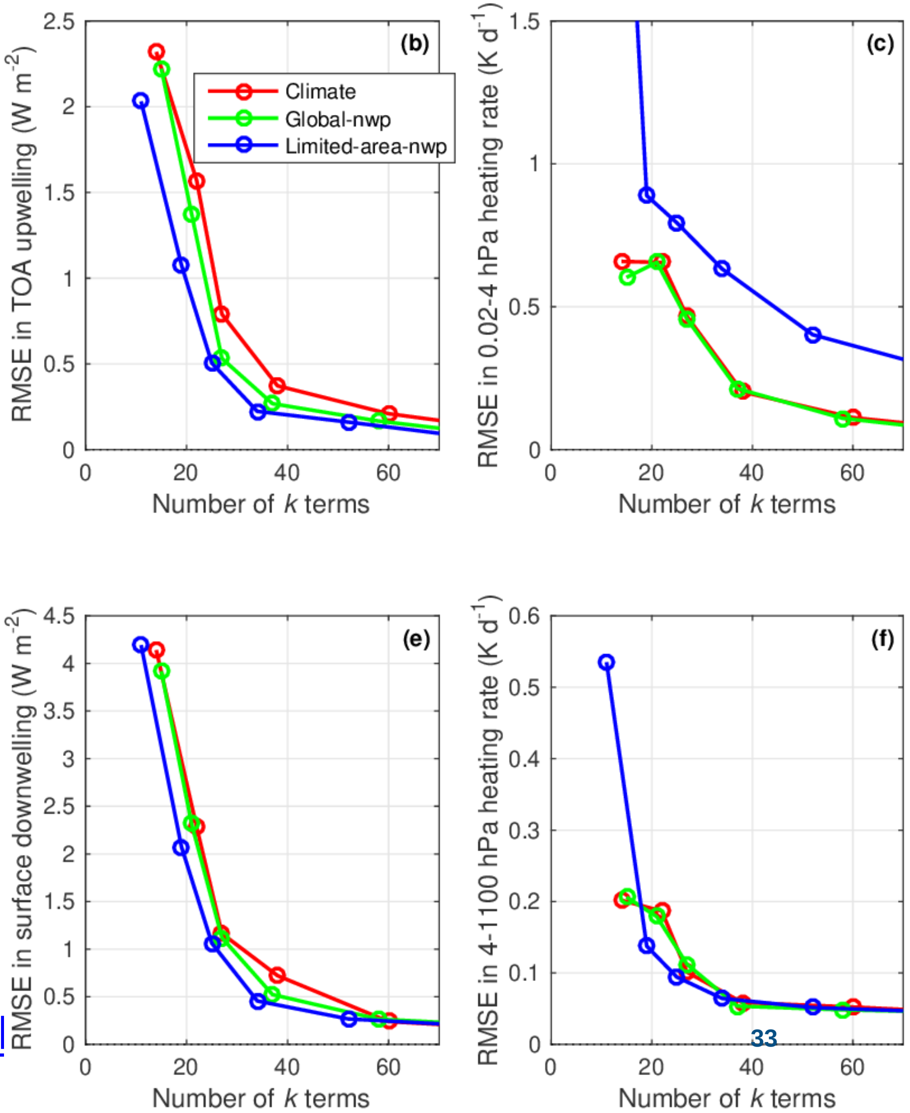

End of part 2

Discussion of next steps

- GMD protocol paper has just received second review, will be revised in the coming few weeks, and one of the reviewers raised a question of the scope of CKDMIP: should it include the effect of uncertainties in spectroscopy?
- What is a realistic timeline for gathering contributions from all models?
- What is a realistic timeline to a CKDMIP results paper?
- Making things more complicated (may be possible without more data from participants)
  - Clouds & aerosols
  - Spectrally varying surface albedo and emissivity
  - Non-LTE? Quantifying mesosphere heating rates a bit misplaced if non-LTE missing?
- Other science questions that could be answered?
- See other insightful comments from one of the GMD referees e.g. why isn't there a formal theory for how to optimally discretize a *k* distribution?
- Next meeting: date and purpose?

Should CKDMIP tackle the impact of spectroscopic uncertainties?

Reviewer comment: *The design of the CKDMIP, particularly the first and second evaluation data sets (table 1 and 2) containing* ***randomly selected realistic thermodynamics profiles, is going to make it much harder to search for systematic errors associated with the treatment of water vapor than is necessary*** *or feasible. Since water vapor is by far the dominant radiatively active species in both the shortwave and the longwave, and since the literature cited in the first major comment above shows that there is still* ***significant spread in the accuracy of the parameterization of near-IR H2O absorption*** *across the CMIP ensembles, this is my principal concern regarding the design of CKDMIP. It's really important to be able to look at the change in the k distributions and resulting fluxes and heating rates when water vapor alone is perturbed. There is a simple fix for this, fortunately,* ***if CKDMIP were to also ask for the exact same set of data from each contributing group for the idealized profiles*** *as for the Evaluation-1 and, ultimately, Evaluation-2 datasets.*

- Should CKDMIP be limited to algorithmic problem of formulating a CKD model *given a spectroscopic database?* Previous intercomparisons have always mixed algorithmic and spectroscopic differences
- Should uncertainties in spectroscopy (especially in water vapour) be introduced into CKDMIP?
- Will they be present in CKDMIP inadvertently because some participants are not using the same spectroscopy, and what can we do about it?

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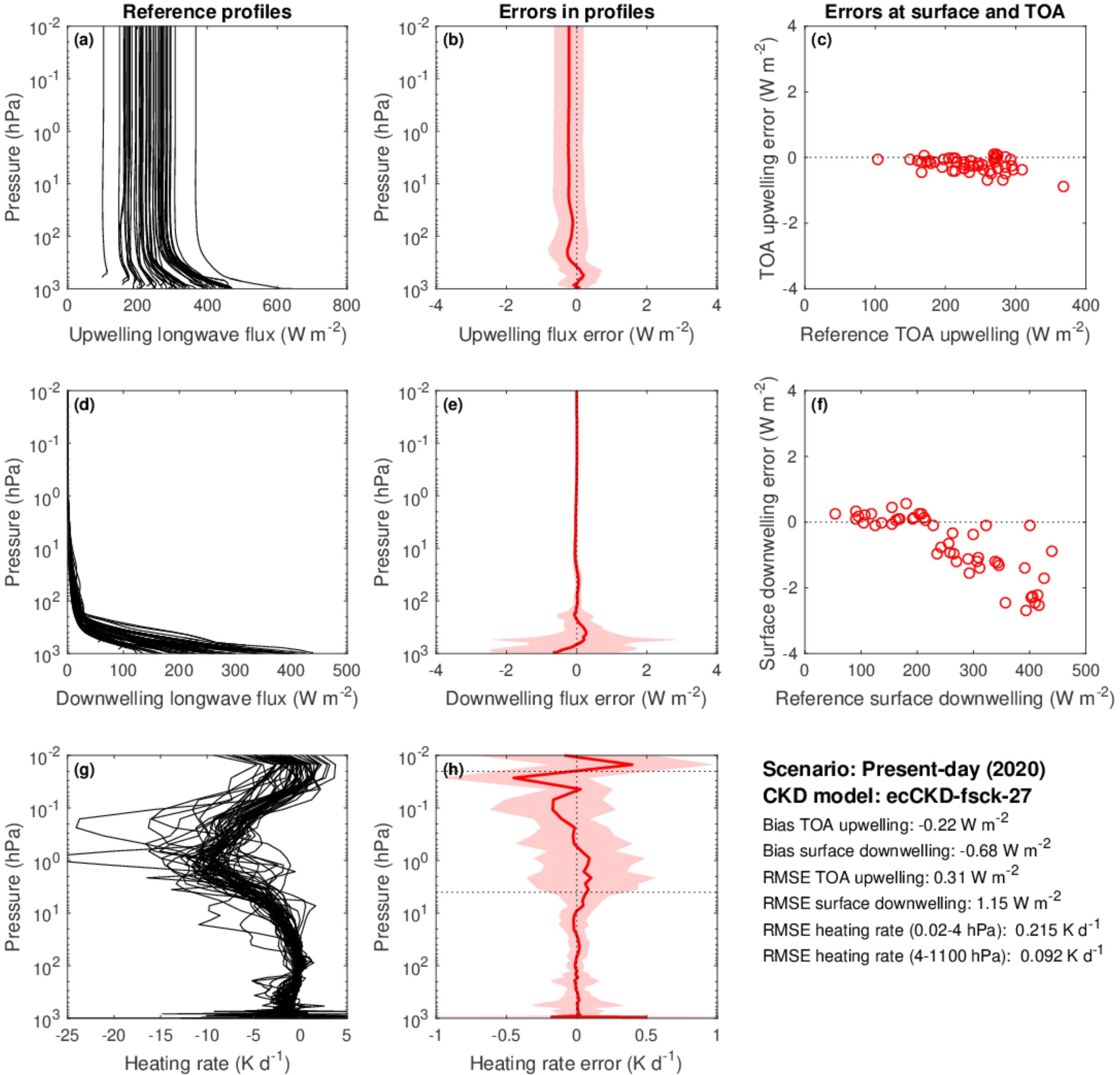
Longwave ecCKD

- climate-fsck-27



Scenario: Present-day (2020)

CKD model: ecCKD-fsck-27

Bias TOA upwelling: -0.22 W m^{-2}

Bias surface downwelling: -0.68 W m^{-2}

RMSE TOA upwelling: 0.31 W m^{-2}

RMSE surface downwelling: 1.15 W m^{-2}

RMSE heating rate (0.02-4 hPa): 0.215 K d^{-1}

RMSE heating rate (4-1100 hPa): 0.092 K d^{-1}

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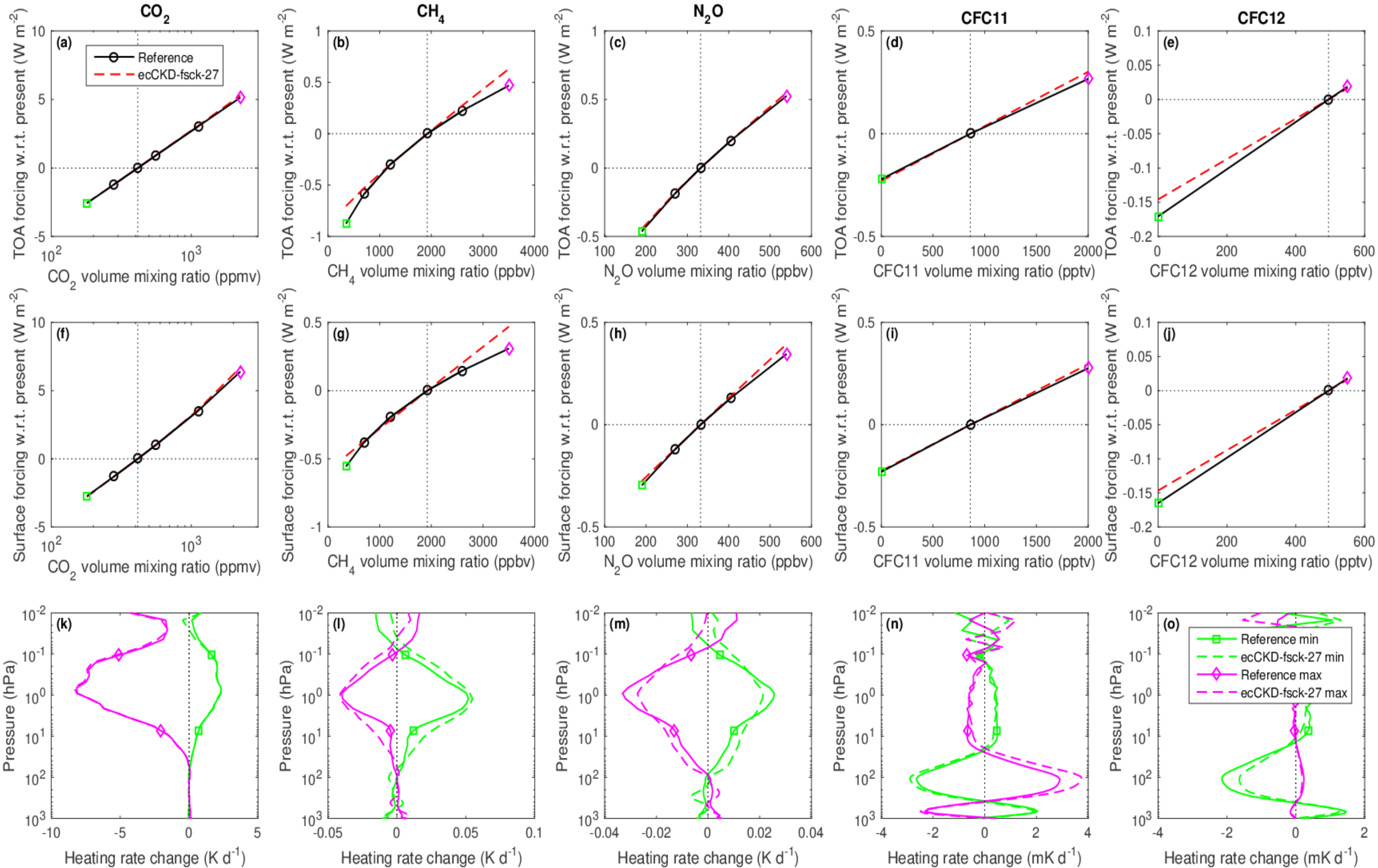
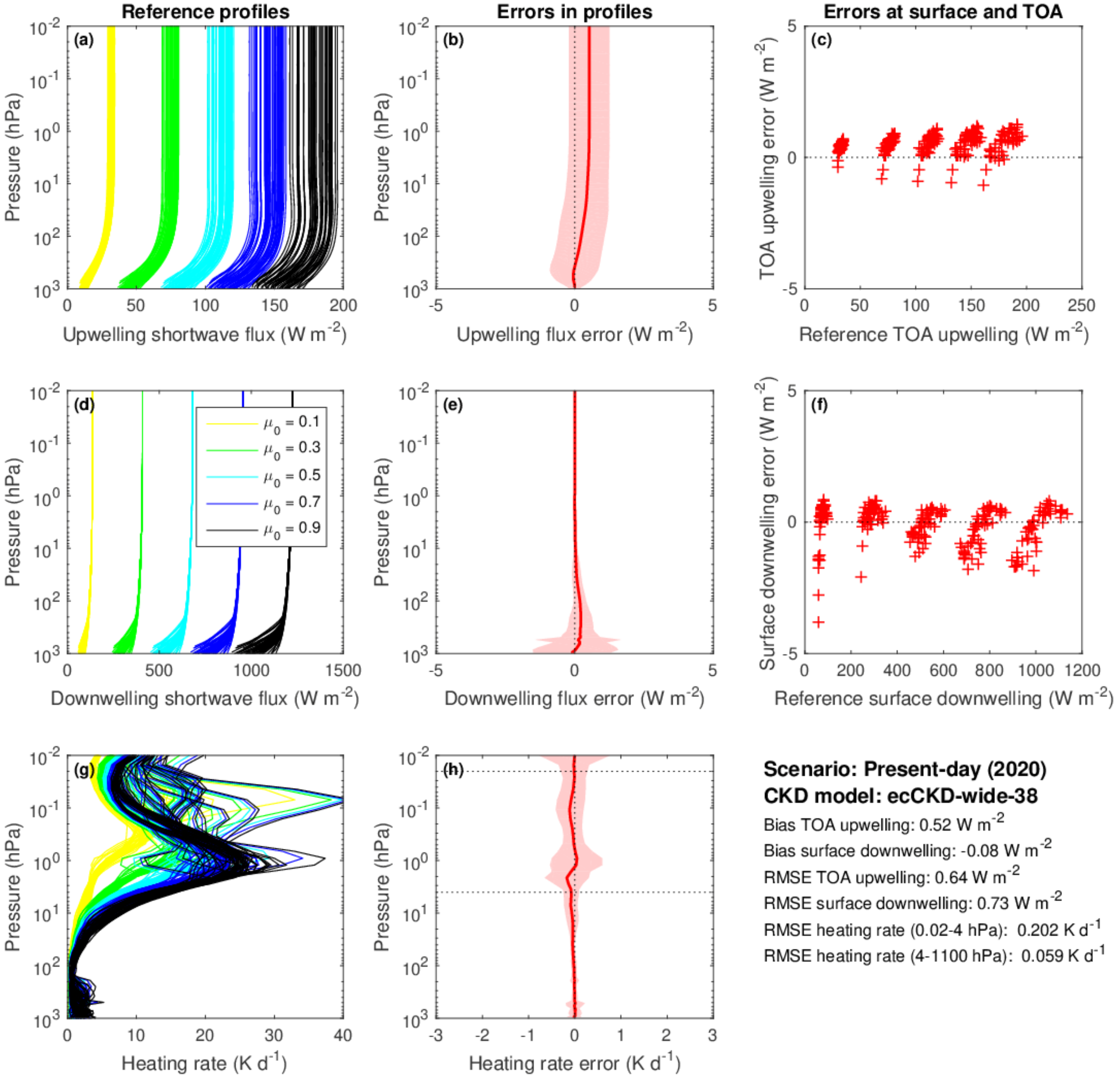
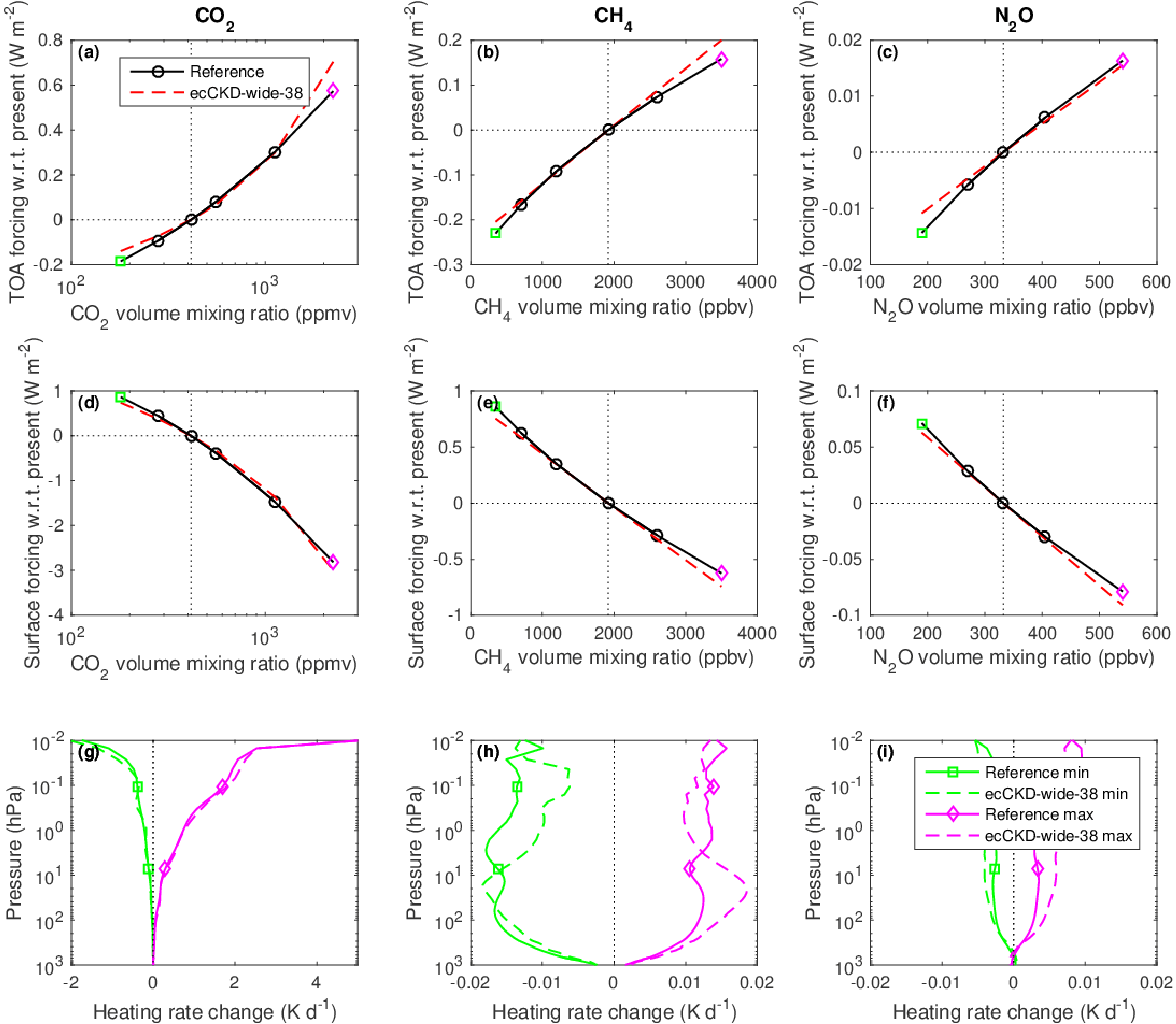


CO2
CH4
N2O
CFC11
CFC12
Reference
ecCKD-fsck-27
TOA forcing w.r.t. present (W m-2)
Surface forcing w.r.t. present (W m-2)
CO2 volume mixing ratio (ppmv)
CH4 volume mixing ratio (ppbv)
N2O volume mixing ratio (ppbv)
CFC11 volume mixing ratio (pptv)
CFC12 volume mixing ratio (pptv)
Pressure (hPa)
Heating rate change (K d-1)
Heating rate change (mK d-1)
Reference min
ecCKD-fsck-27 min
Reference max
ecCKD-fsck-27 max

Shortwave ecCKD

- climate-wide-38




CO2
CH4
N2O
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
Reference
ecCKD-wide-38
TOA forcing w.r.t. present (W m-2)
Surface forcing w.r.t. present (W m-2)
CO2 volume mixing ratio (ppmv)
CH4 volume mixing ratio (ppbv)
N2O volume mixing ratio (ppbv)
Pressure (hPa)
Heating rate change (K d-1)
Reference min
ecCKD-wide-38 min
Reference max
ecCKD-wide-38 max

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