Impact of Multiple Scattering on Infrared Radiative Transfer Involving Ice Clouds

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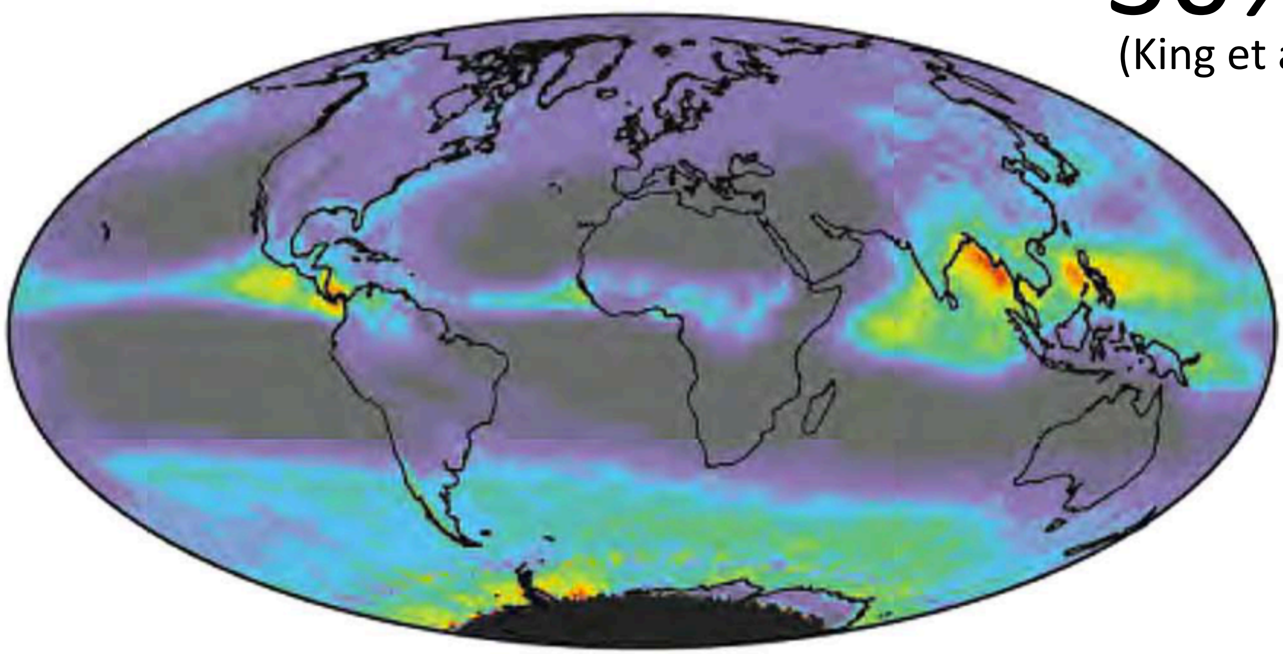
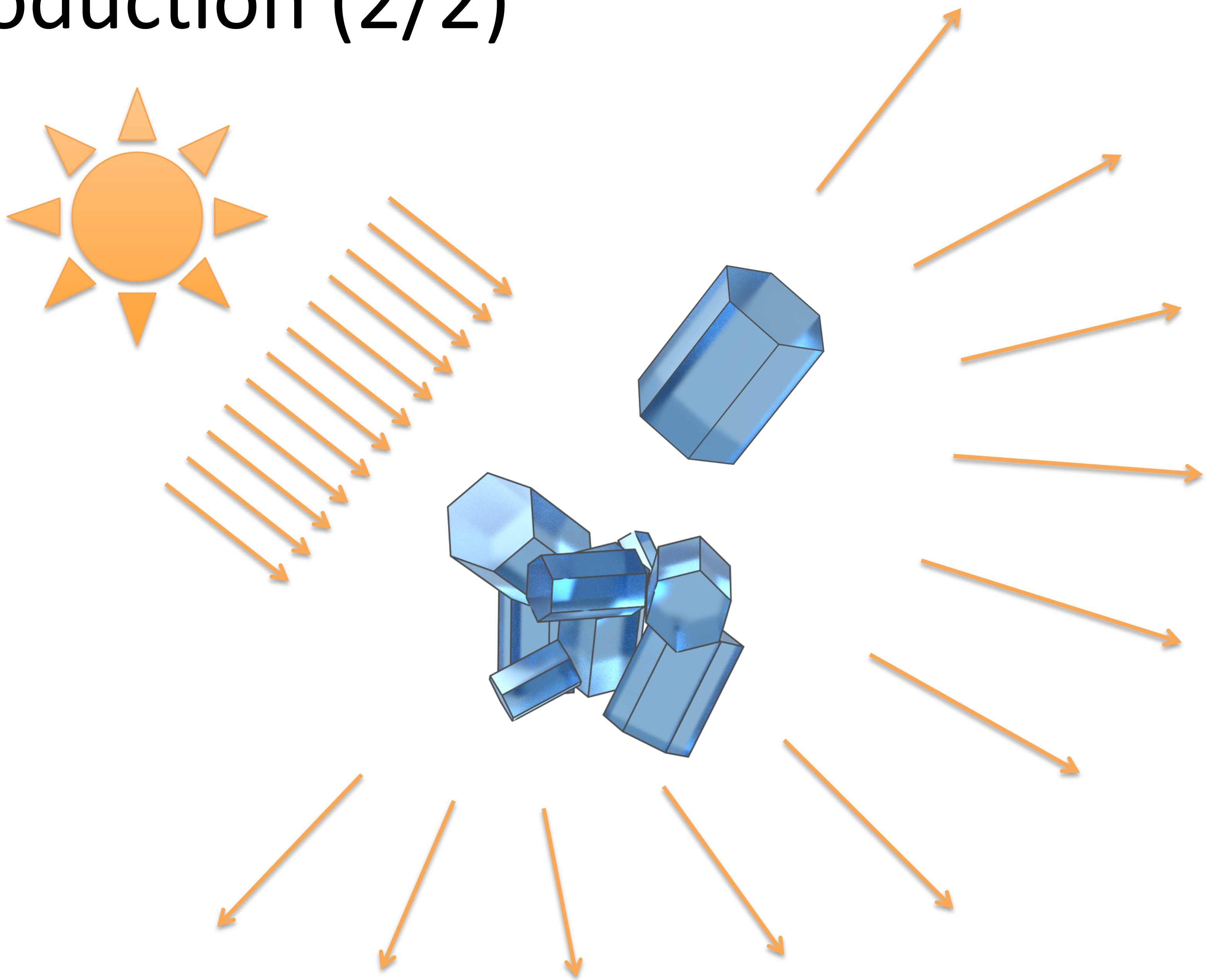
Introduction (1/2)

30%
(King et al. 2013)



Introduction (2/2)



Objective (1/2)

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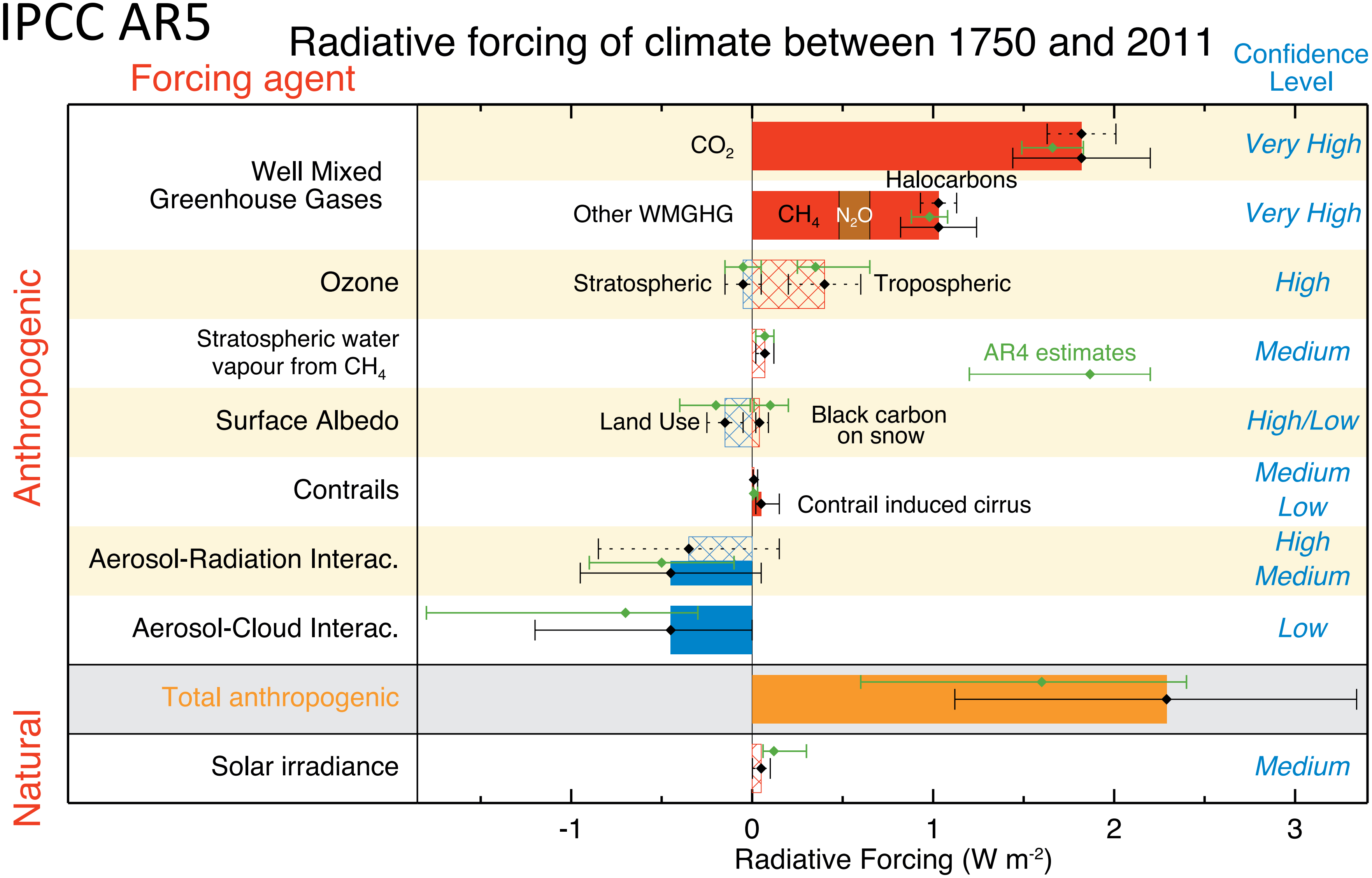

Objective (2/2)

Part 1: Applying MODIS Collection 6 (MC6) Parameterization to RRTMG_LW

Part 2: Estimating Longwave Flux Difference (ΔF) Because of Ice Cloud

Part 1 (1/2): MC6 and Fu Parameterizations

Ice Cloud Models

- MC6
- Fu (Fu et al. 1998)

RRTMG_LW

16 Spectral Bands
($10 – 3250\ cm^{-1}$)
(Mlawer et al. 1997)

Results

- Upward Flux (F^u)
- Downward Flux (F^d)

Part 1 (1/2): MC6 and Fu Parameterizations

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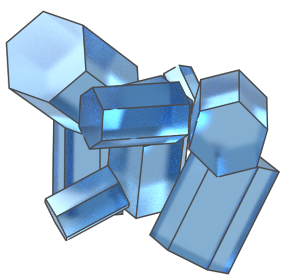
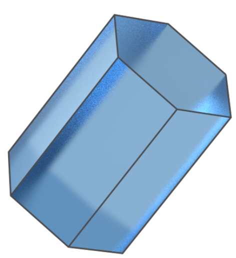


MC6 Ice Cloud Model
- Aggregate of Columns
- Roughened Surface

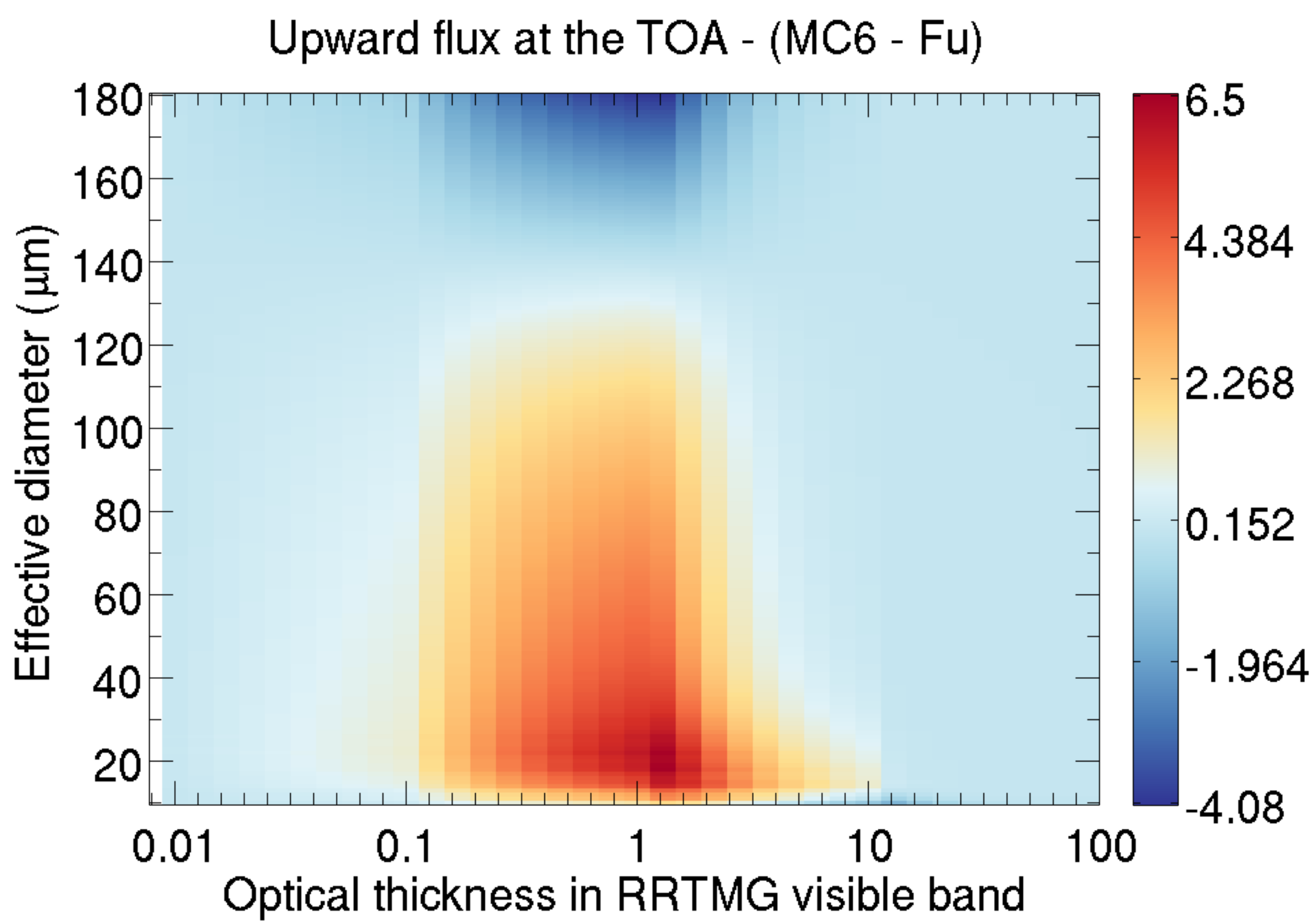


Fu Ice Cloud Model
- Single Hexagonal Column
- Smooth Surface

Part 1 (2/2): Flux Difference

Midlatitude Summer (MLS)

$$\Delta F = F_{MC6} - F_{Fu}$$

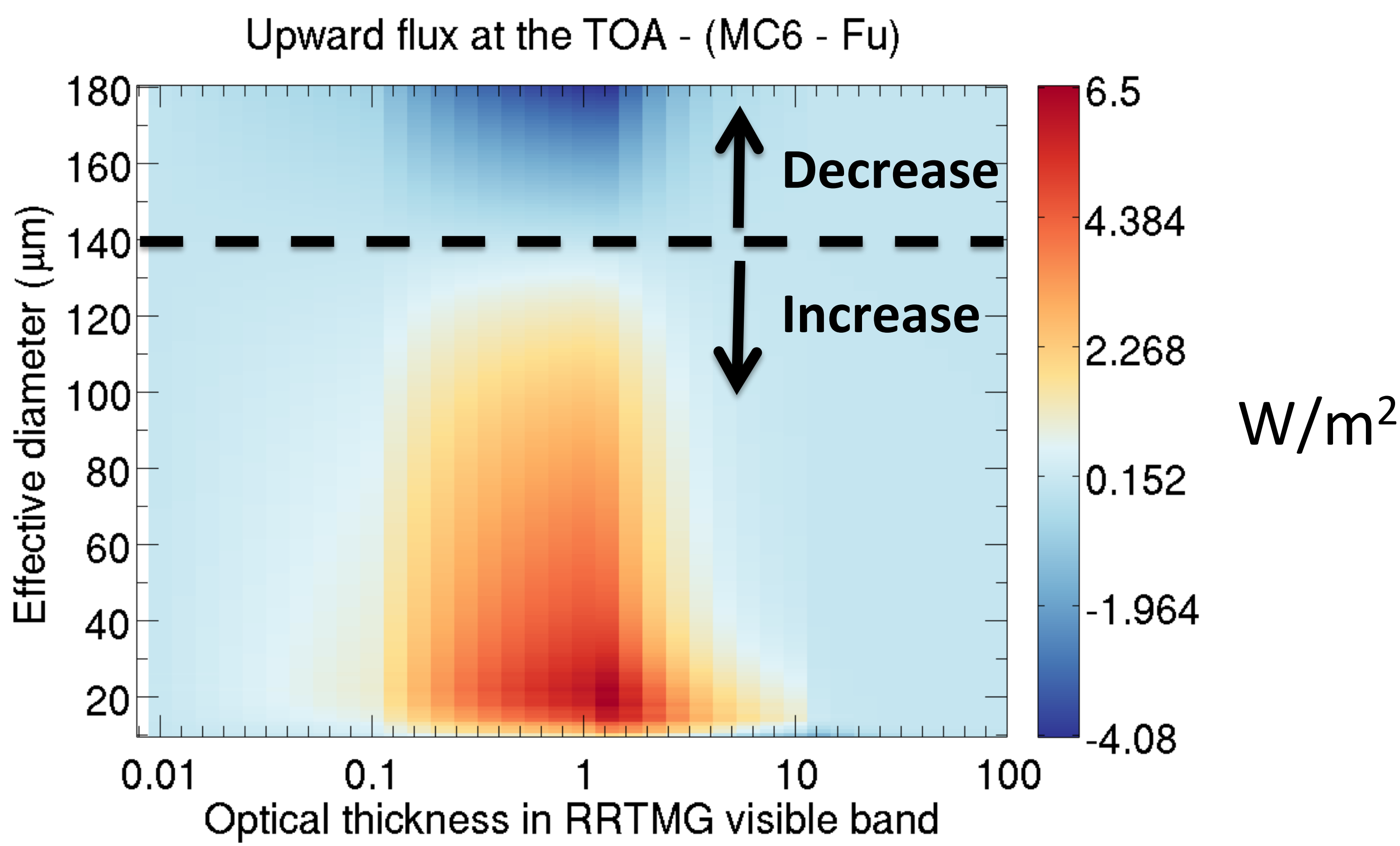


W/m²

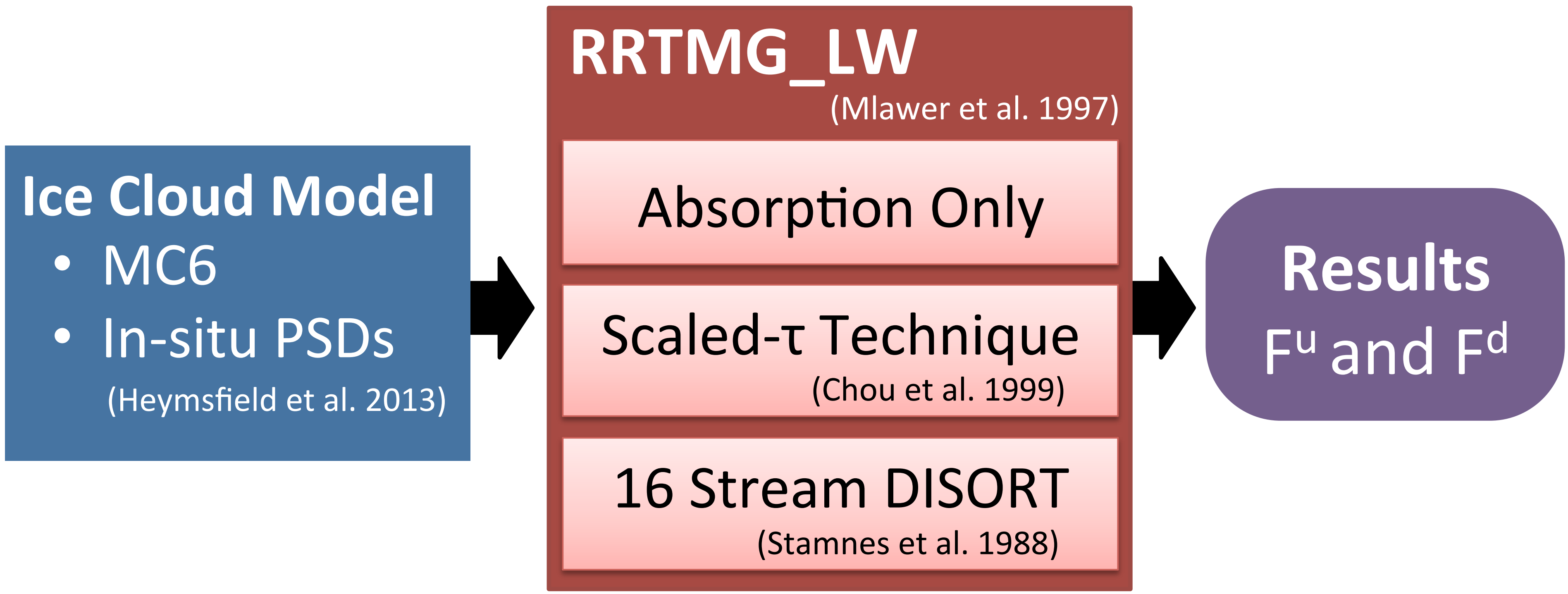
Part 1 (2/2): Flux Difference

Midlatitude Summer (MLS)

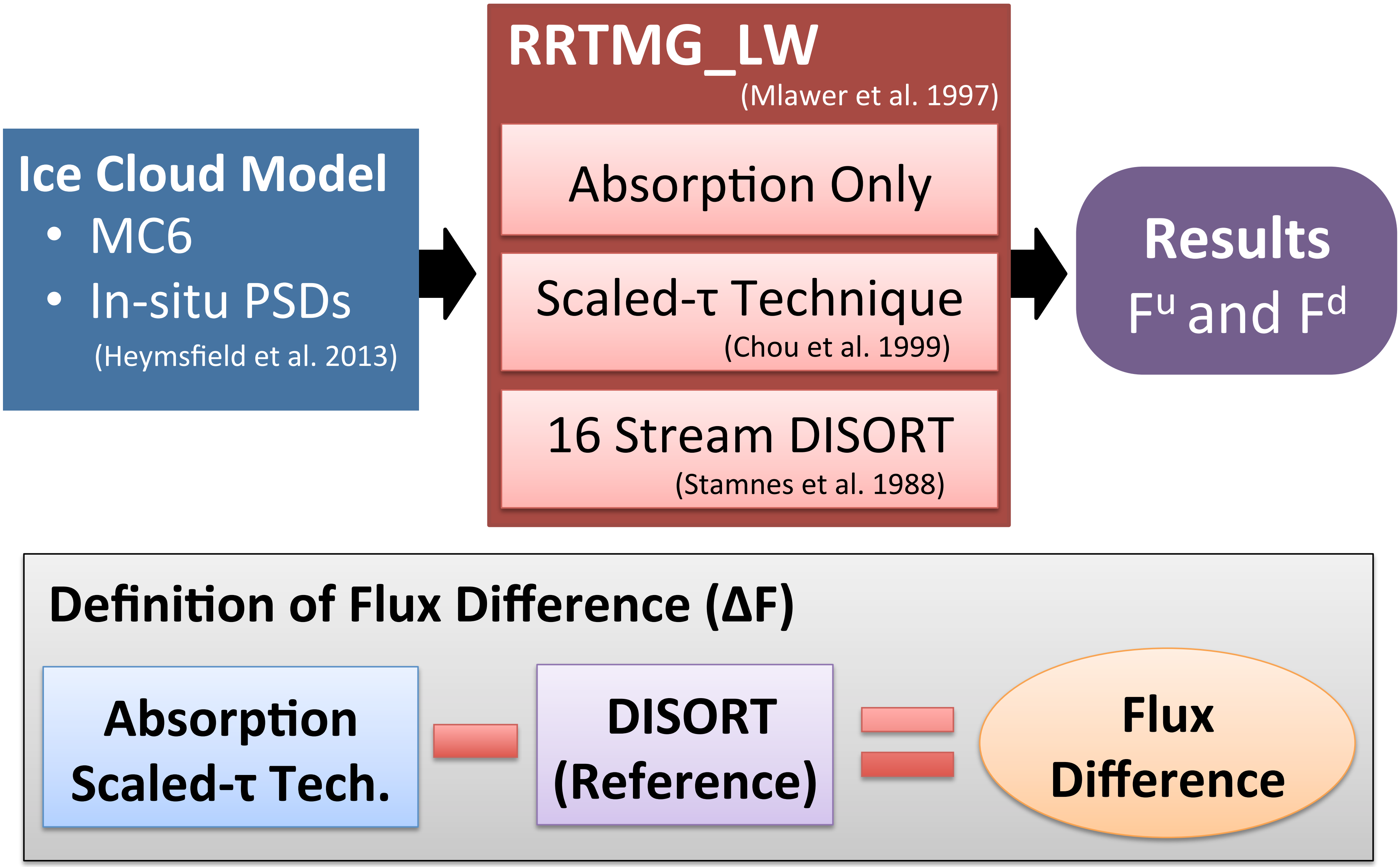
$$\Delta F = F_{MC6} - F_{Fu}$$



Part 2 (1/4): Model Settings and Flux Difference

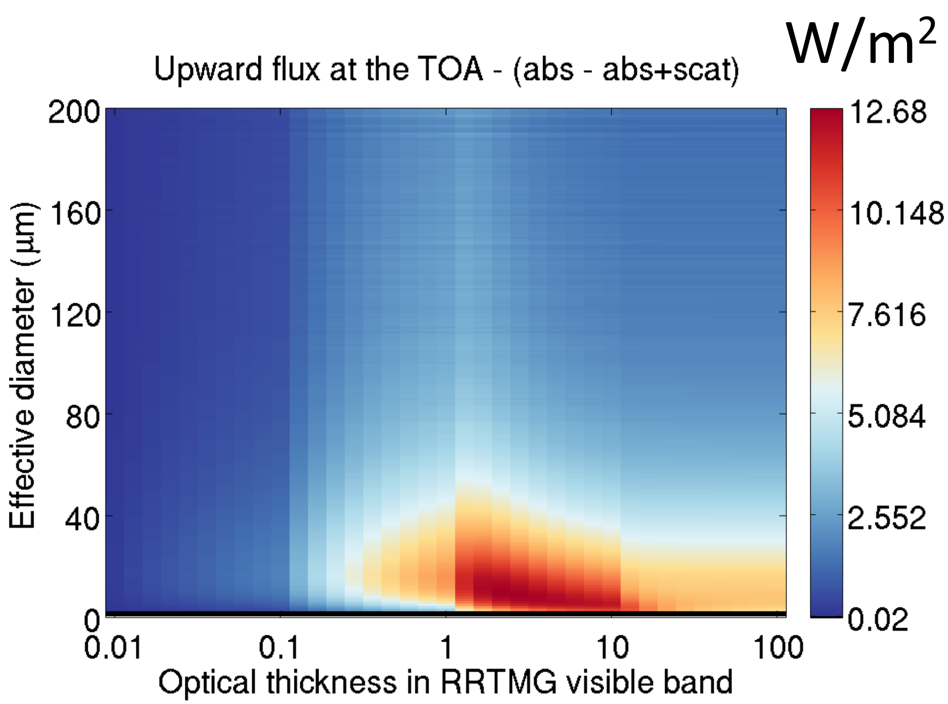


Part 2 (1/4): Model Settings and Flux Difference

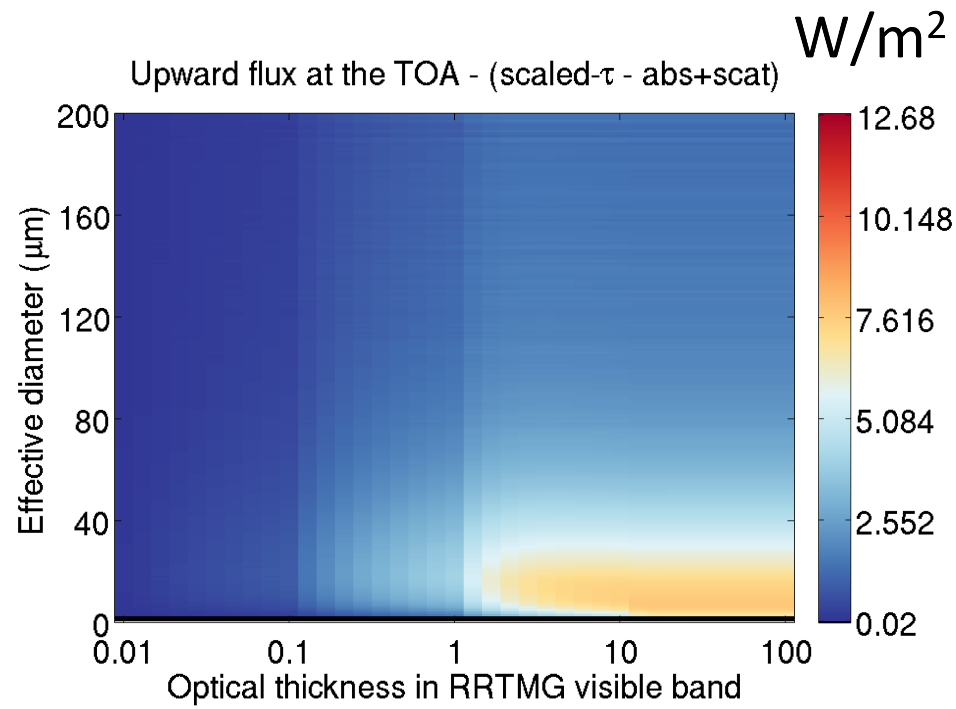


Part 2 (2/4): Flux Difference under MLS

(a) Abs. – DISORT

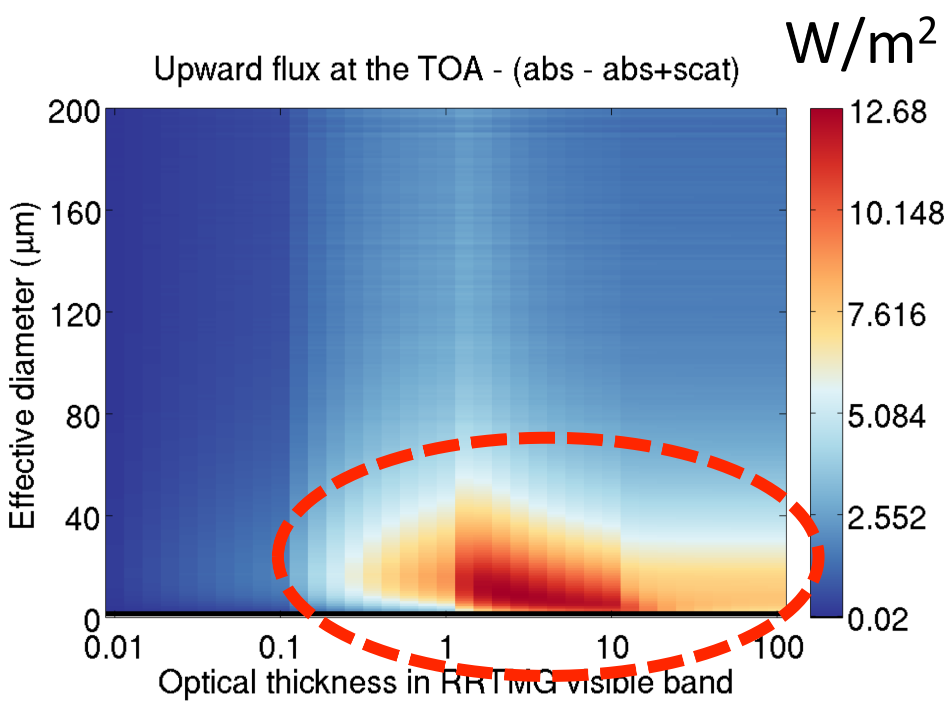


(b) Scaled-τ – DISORT



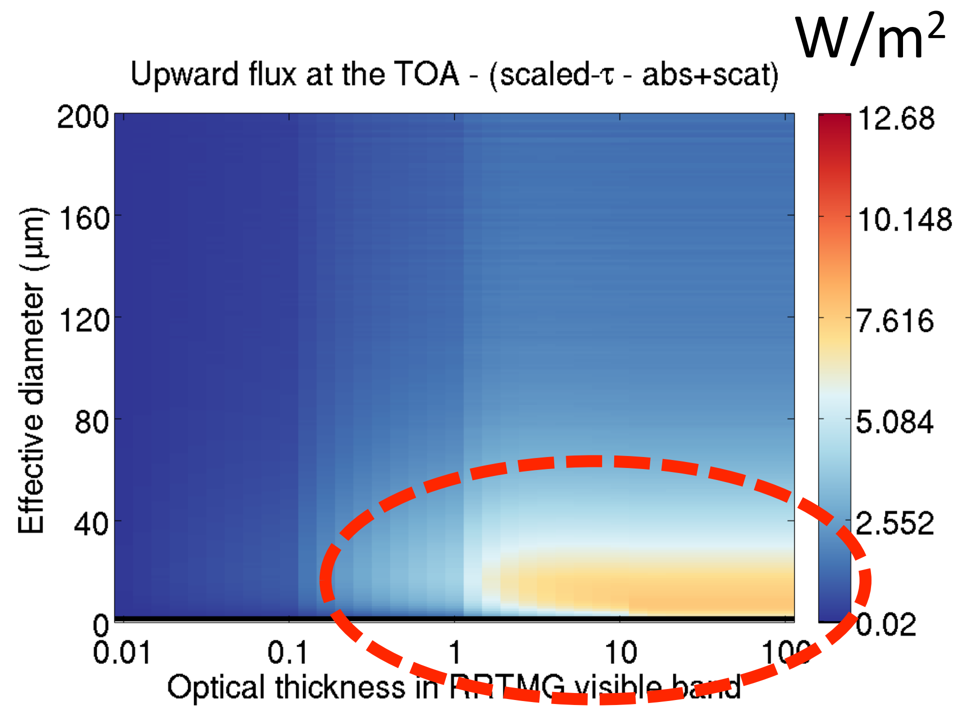
Part 2 (2/4): Flux Difference under MLS

(a) Abs. – DISORT



12.6 W/m²

(b) Scaled-τ – DISORT



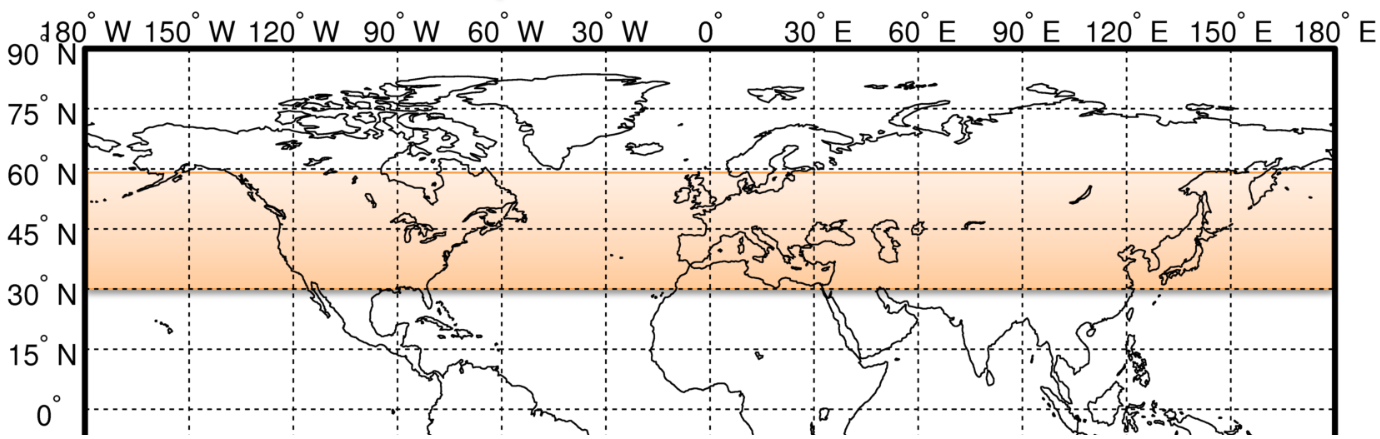
7.7 W/m²

Part 2 (3/4): Flux Difference Estimation

Aqua MODIS Collection 6
Level 3 Monthly Averaged Data

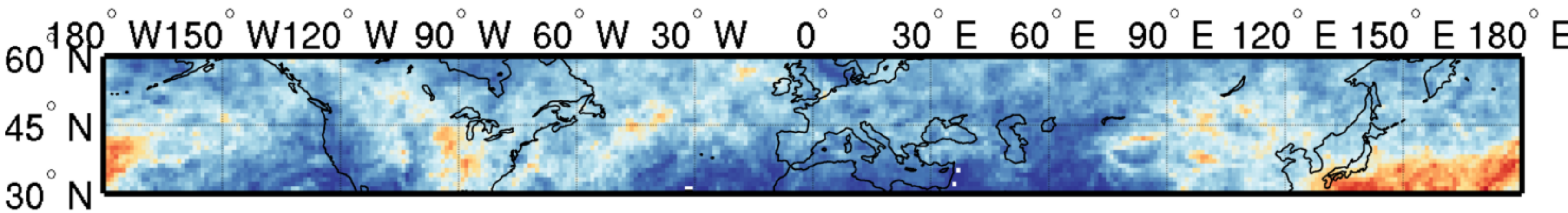
Ice Cloud:
Optical Thickness
Effective Diameter
Cloud Fraction

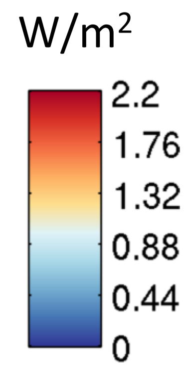
June, 2014 (MLS)



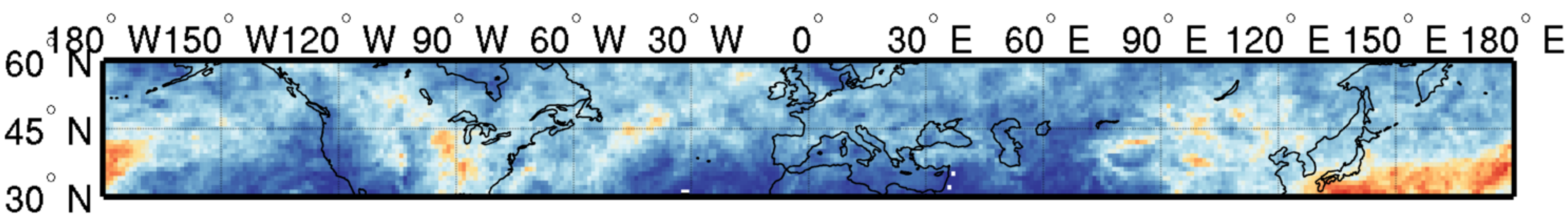
Part 2 (4/4): Flux Difference Estimation

(a) Abs. – DISORT





(b) Scaled-τ – DISORT



Conclusions

Applying MC6 Parameterization to RRTMG_LW

- Overall, the warming effect due to ice clouds is smaller with the MC6 model than with the Fu model.

Estimating Longwave ΔF Because of Ice Cloud

- A radiative transfer model implemented with light scattering process is needed in climate simulations.

Acknowledgements

- This study is supported by the U.S. Department of Energy (DOE) under Grant DE-SC0013080 managed by Dr. Dorothy Koch.
- The simulations are performed by computational resources provided by the Texas A&M Supercomputing Facility (**http://sc.tamu.edu**).

RRTMG_LW

(GCM version of Rapid Radiative Transfer Mode in Longwave)
From AER company http://rtweb.aer.com/rrtm_frame.html

- Ice Cloud Parameterization
  - Fu-Liou parameterization
  - From Fu et al. 1998
- Radiative Transfer Process
  - Absorption only (diffusivity factor 1.66; or angle 53°)
- 16 Longwave Spectral Bands

$$t_F \approx e^{-\tau/\bar{\mu}} \quad 1/\bar{\mu} = 1.66$$

t_F : flux transmittance
τ : optical thickness
$\bar{\mu}$: effective zenith angle; cos(53°)

Adjust with total column water in some bands

RRTMG LW	Band01	Band02	Band03	Band04	Band05	Band06	Band07	Band08
Wavenumber (cm^{-1})	10 - 350	350 - 500	500 - 630	630 - 700	700 - 820	820 - 980	980 - 1080	1080 - 1180
Wavelength (μm)	1000 - 28.57	28.57 - 20.00	20.00 - 15.87	15.87 - 14.29	14.29 - 12.20	12.20 - 10.20	10.20 - 9.26	9.26 - 8.47
RRTMG LW	**Band09**	**Band10**	**Band11**	**Band12**	**Band13**	**Band14**	**Band15**	**Band16**
Wavenumber (cm^{-1})	1180 - 1390	1390 - 1480	1480 - 1800	1800 - 2080	2080 - 2250	2250 - 2380	2380 - 2600	2600 - 3250
Wavelength (μm)	8.47 - 7.19	7.19 - 6.76	6.76 - 5.56	5.56 - 4.81	4.81 - 4.44	4.44 - 4.20	4.20 - 3.85	3.85 - 3.08

Ice Particle Model – MC6

- MODIS Collection 6 (MC6)
  - Aggregated hexagonal columns
  - $\sigma^2 = 0.5$ surface roughness
  - From Yang et al. 2013
- Refractive Indices of Ice
  - From Warren and Brandt 2008
- Particle Size Distribution (PSD)
  - Ice cloud (temperature ≤ -40˚C)
  - 14406 PSDs (11 field campaigns)
  - From http://www.ssec.wisc.edu/ice_models/microphysical_data.html
- Baum (2011) found that utilizing severely roughened ice particles best compares with observations from CALIOP (Cloud aerosol Lidar with Orthogonal Polarization).
- Without considering surface roughness would cause 1-2 Wm^{-2} on global mean shortwave cloud radiative effect (Yi et al. 2013).

Field Campaign	Year	Number of PSDs
ARM-IOP	2000	1420
TRMM KWAJEX	1999	201
CRYSTAL-FACE	2004	221
SCOUT	2005	358
ACTIVE-Monsoons	2005	4268
ACTIVE-Squall Lines	2005	740
ACTIVE-Hector	2005	2583
MidCiX	2004	2968
Pre-AVE	2004	99
MPACE	2004	671
TC-4	2006	877

Ice Particle Model – Fu

- Fu ice particle model
  - Single hexagonal column
  - Smooth particle ($\sigma^2 = 0$ surface roughness)
  - From Fu and Liou 1993, Fu 1996, and Fu et al. 1998
- Refractive Indices of Ice
  - From Warren 1984, and Gosse et al. 1996
- Particle Size Distribution (PSD)
  - 28 PSDs (6 field campaigns)

Field Campaign	Year	Number of PSDs
Heymsfield and Platt	1984	8
Takano and Liou	1989	4
FIRE-IFO-I	1986	5
FIRE-IFO-II	1991	2
CEPEX: IWC	1993	4
CEPEX: April 4	1993	5

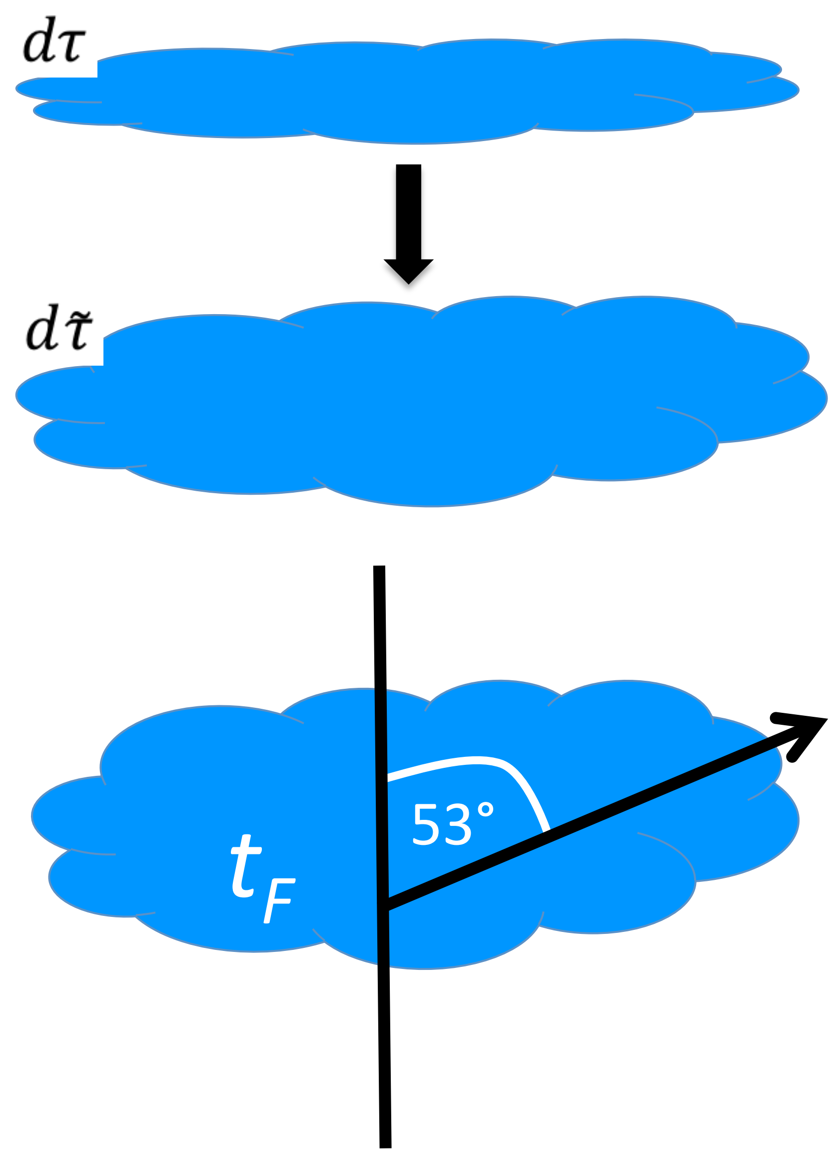
Scaled-τ Technique (Chou et al. 1999)

Flux transmittance $t_F \approx e^{-\tau/\bar{\mu}}$

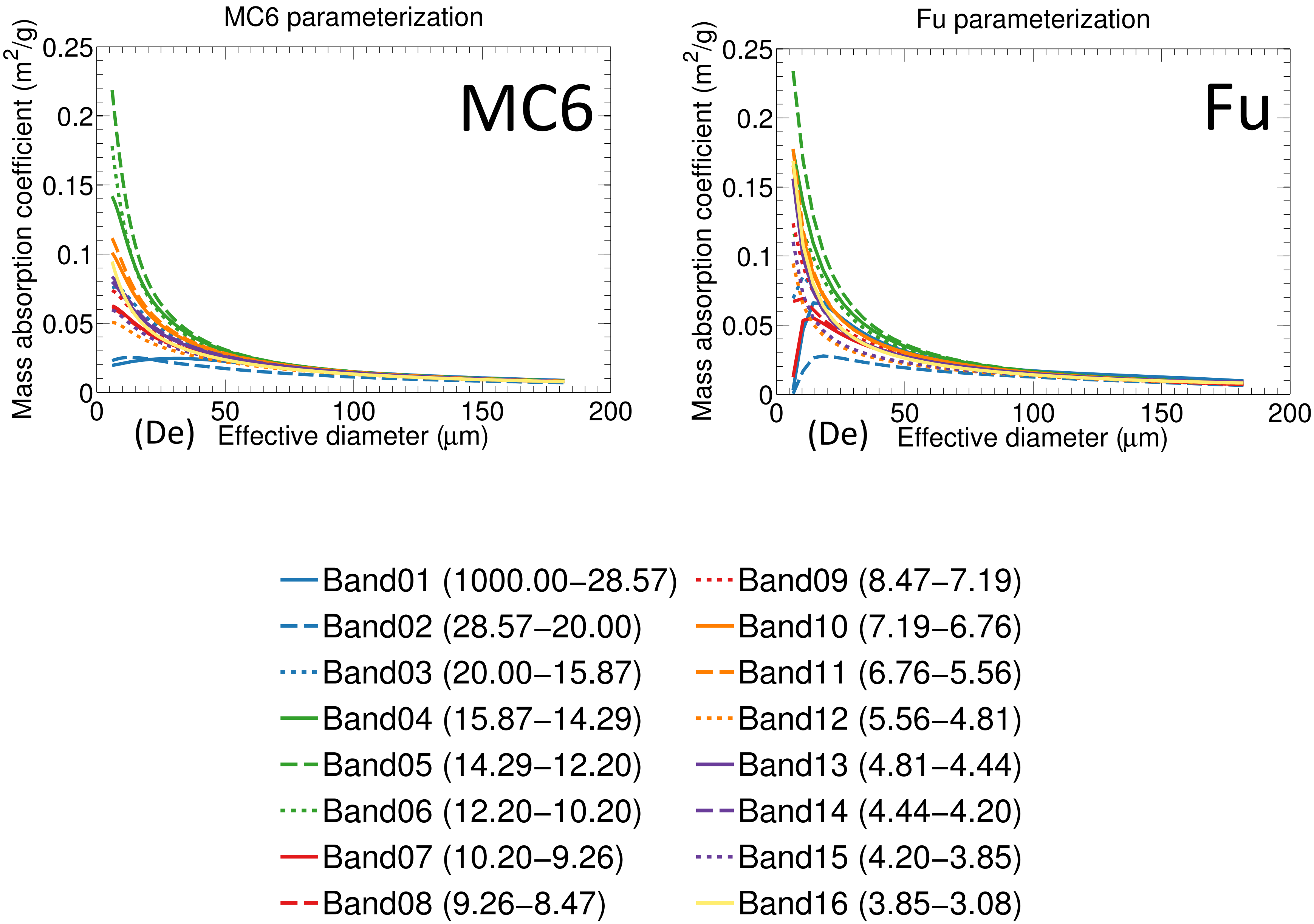
Adjusted optical thickness $d\tilde{\tau} = (1 - \omega f)d\tau$

Fraction of forward scattering $f = \sum_{i=1}^{4} a_i g^{i-1}$

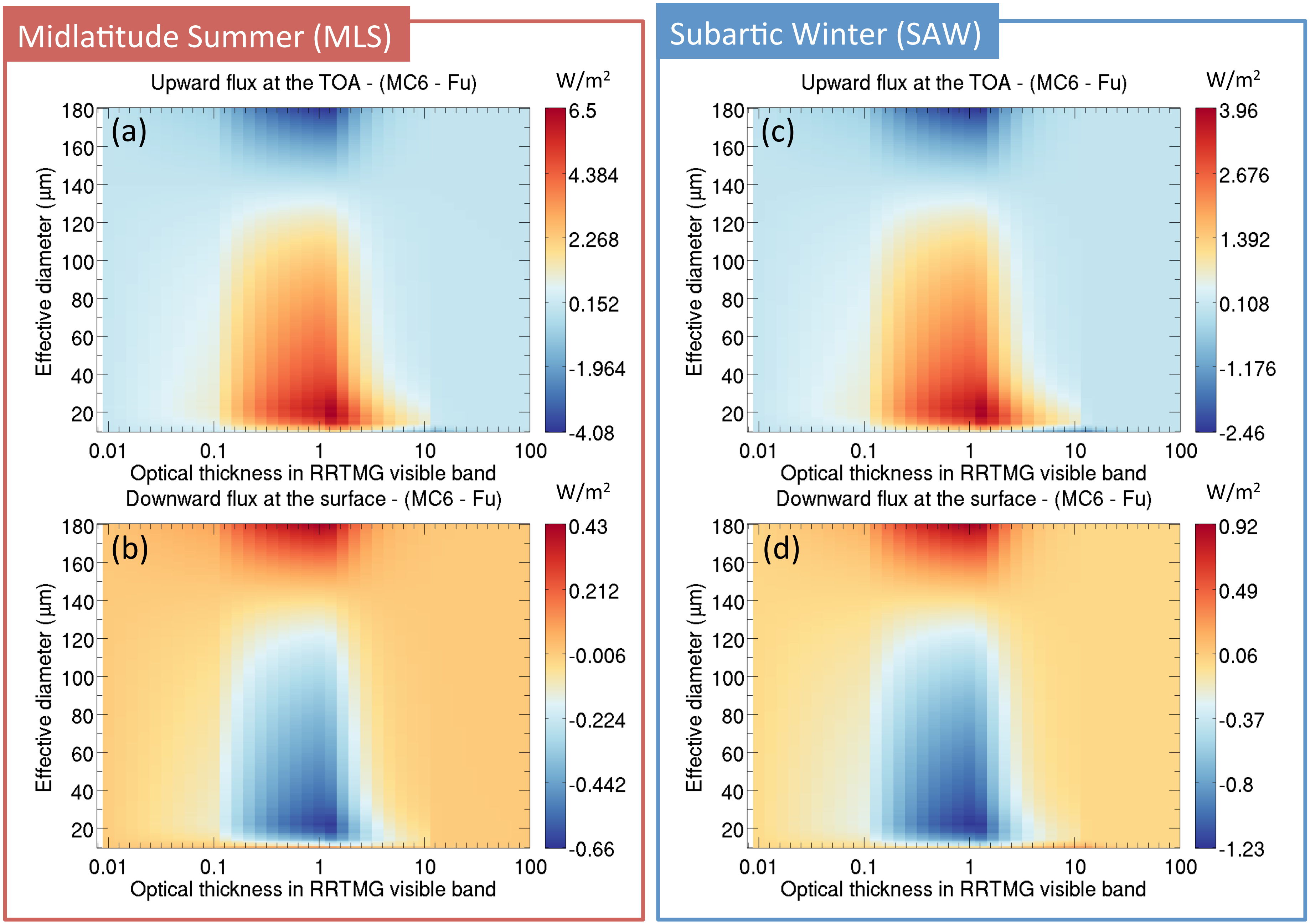
Diffusivity factor $1/\bar{\mu} = 1.66$



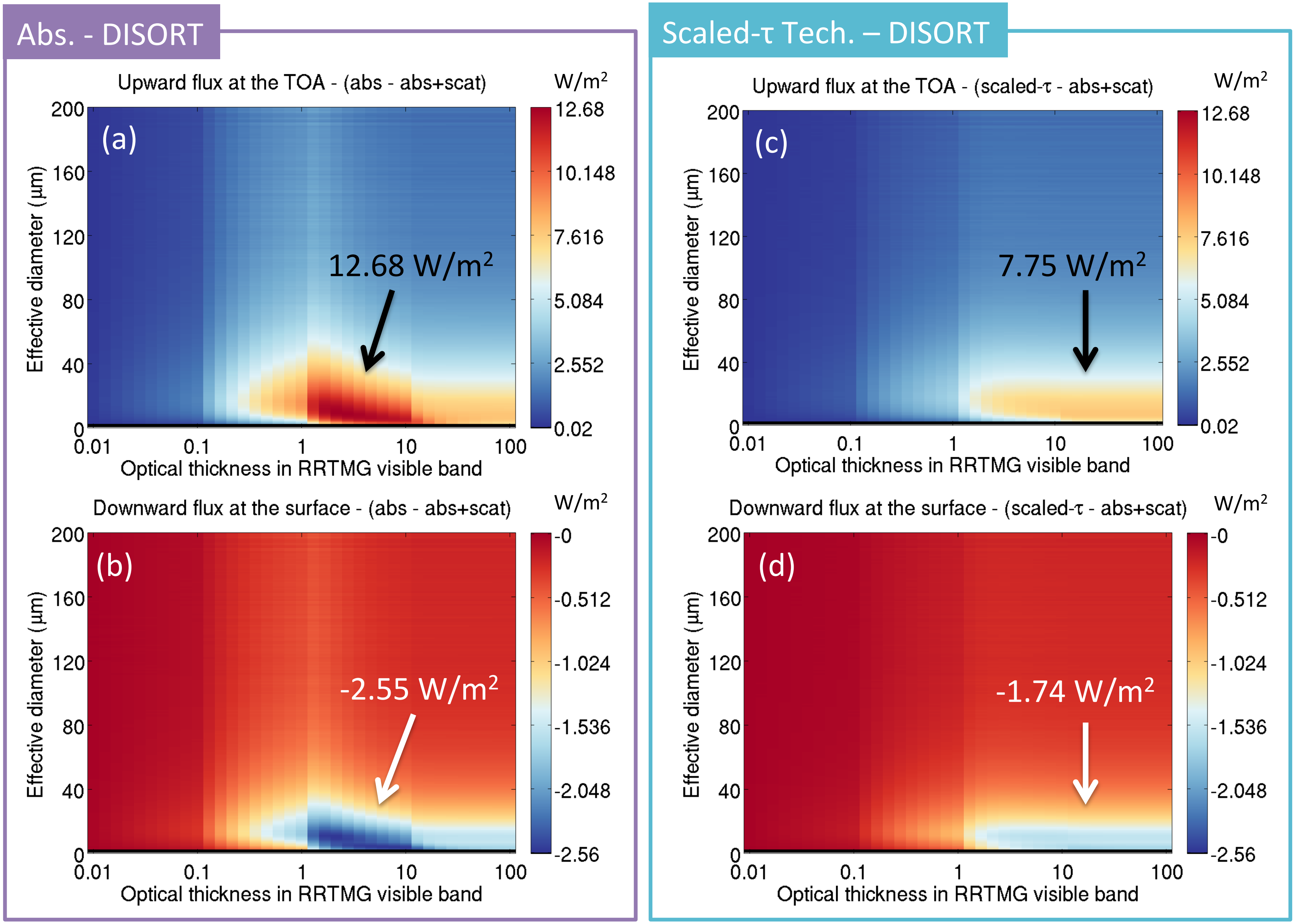
τ : optical thickness
$\bar{\mu}$: effective zenith angle; cos(53°)
ω : single-scattering albedo
g : asymmetry factor
a_i : polynomial coefficients


MC6 parameterization
MC6
Mass absorption coefficient (m^2/g)
0
0.05
0.1
0.15
0.2
0.25
0
50
100
150
200
(De)
Effective diameter (μm)
Fu parameterization
Fu
Mass absorption coefficient (m^2/g)
0
0.05
0.1
0.15
0.2
0.25
0
50
100
150
200
(De)
Effective diameter (μm)
Band01 (1000.00–28.57)
Band02 (28.57–20.00)
Band03 (20.00–15.87)
Band04 (15.87–14.29)
Band05 (14.29–12.20)
Band06 (12.20–10.20)
Band07 (10.20–9.26)
Band08 (9.26–8.47)
Band09 (8.47–7.19)
Band10 (7.19–6.76)
Band11 (6.76–5.56)
Band12 (5.56–4.81)
Band13 (4.81–4.44)
Band14 (4.44–4.20)
Band15 (4.20–3.85)
Band16 (3.85–3.08)

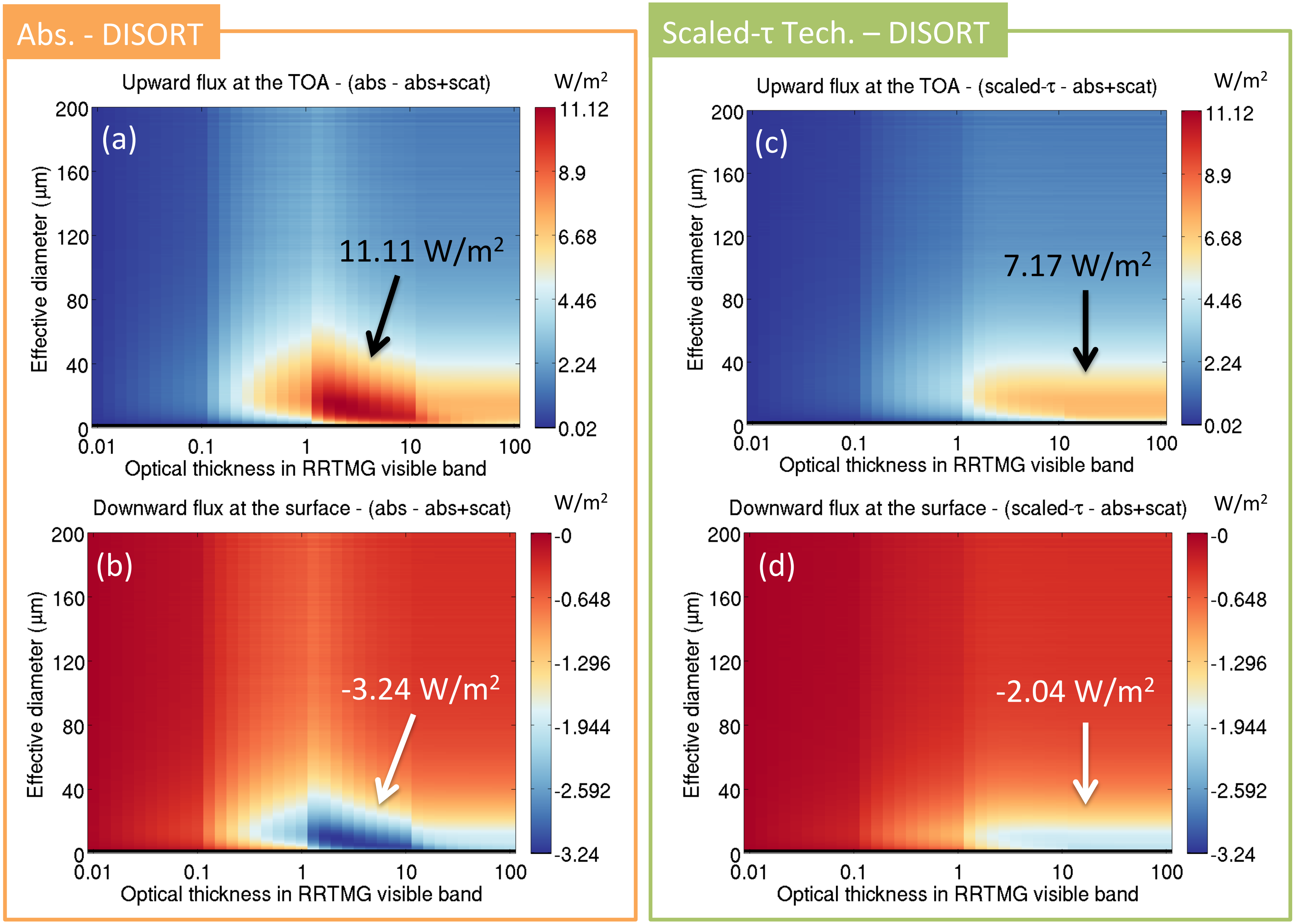
Part 1: Flux Difference (F_{MC6} - F_{Fu})



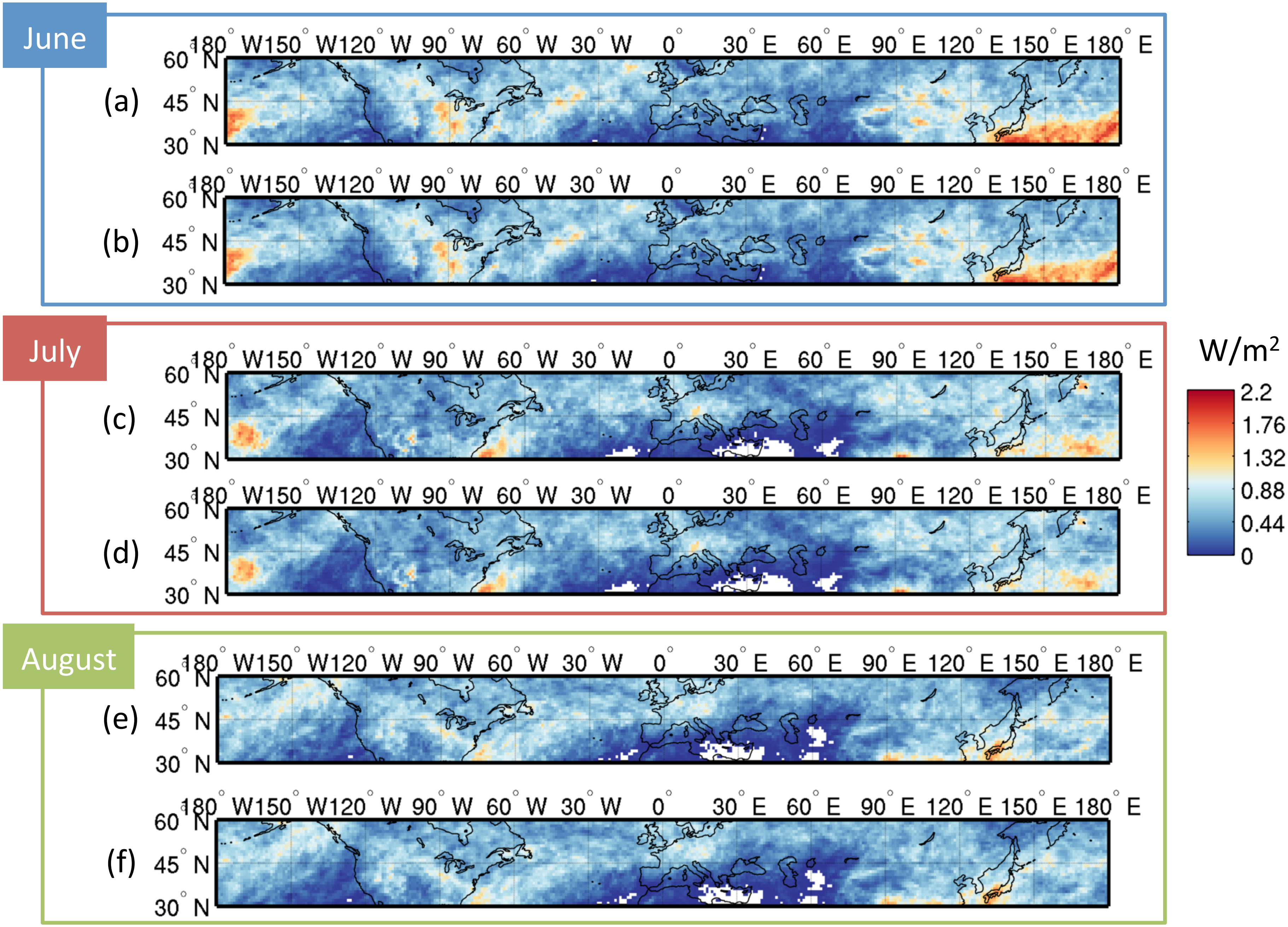
Part 2: ΔF under MLS condition



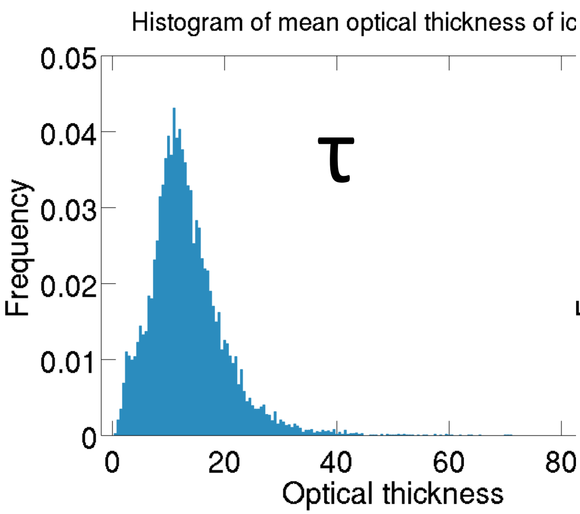
Part 2: ΔF under SAW condition

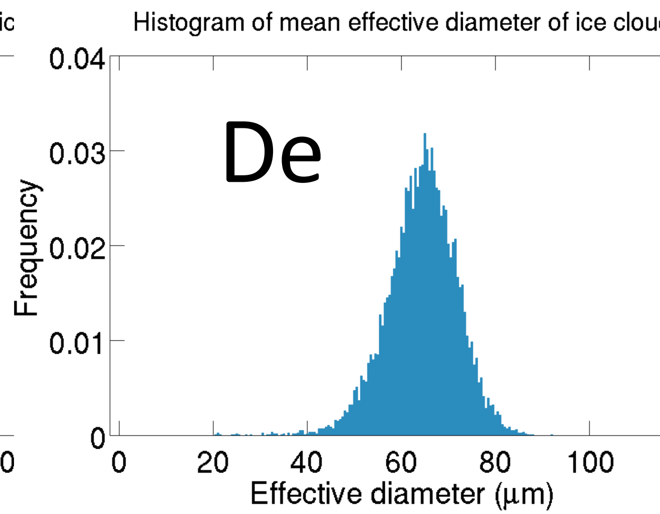


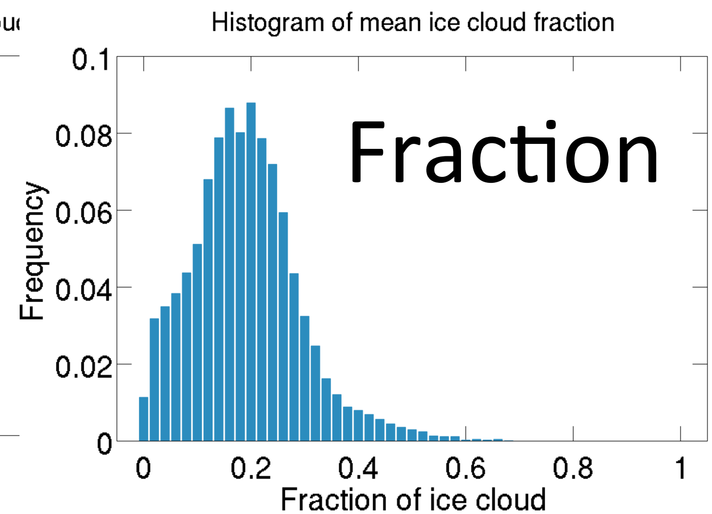
Part 2: Estimation of ΔF in MLS



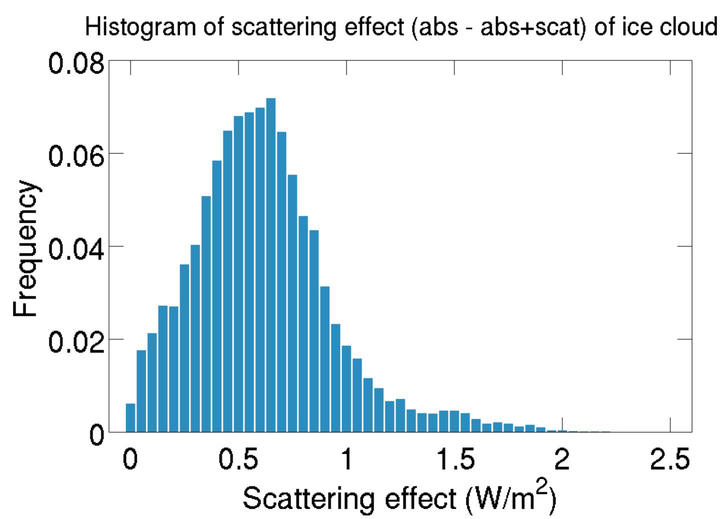
MYD08_M3 2014 June







Abs. - DISORT



Scaled - DISORT