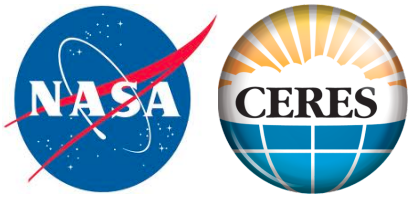
CERES Science Team Meeting 2015, May 5-7, NASA Langley Research Center



Correction of Directional Effects of Incident Radiation on Ocean Surface for CERES Longwave Irradiance Computations

Seung-Hee Ham[1], Seiji Kato[2], and Fred Rose[1]

1 Science Systems and Applications Inc. (SSAI), Hampton, Virginia, USA
2 NASA Langley Research Center, Hampton, Virginia, USA

Motivation and Objectives

- CERES SYN uses Fu-Liou model (Fu et al., 1997, JAS) for computation of broadband irradiances. This model uses spherical albedo and emissivity for irradiance computation.
- Surface incoming infrared radiance is anisotropic; incoming radiance increases with incoming zenith angle.
- Ocean reflectivity and emissivity change with viewing angle.
- Compare between upward surface irradiances from spherical and directional albedo/emissivity.
- Implement a simple correction factor for spherical albedo and parameterize it for various atmospheric conditions.
- Apply to SYN

Infrared Radiative Transfer

Spherical Mean

$$\langle x \rangle = 2\int_0^1 x(\mu)\mu\, d\mu, \qquad \mu = \cos\theta$$

Directional Emissivity with outgoing angle μ

SFC Upward radiance with outgoing direction μ

$$I(\mu) = 2\int_0^1 I^-(\mu')r(\mu',\mu)\mu' d\mu' + \varepsilon(\mu)B(T_s)$$

Bidirectional Reflectivity with incoming angle μ' and outgoing angle μ

Directional Reflectivity

$$\rho(\mu)=2\int_0^1 r(\mu',\mu)\mu\, d\mu$$

SFC Upward irradiance

$$F = 2\pi\int_0^1 I(\mu)\mu\, d\mu$$

$$= 4\pi\int_0^1\int_0^1 I^-(\mu')r(\mu',\mu)\mu\mu' d\mu\, d\mu' + 2\pi\int_0^1 \varepsilon(\mu)B(T_s)\mu\, d\mu$$

$$= 2\pi\int_0^1 I^-(\mu')\rho(\mu')\mu' d\mu' + 2\pi B(T_s)\int_0^1 \varepsilon(\mu)\mu\, d\mu$$

$$= \pi\left\{\langle \rho I^- \rangle + \langle \varepsilon \rangle B(T_s)\right\}$$

For irradiance computation, we only need ρ(μ), instead of r(μ',μ).

Surface Upward Irradiance in Fu-Liou Model

Delta-two- and four-stream combination method (Fu et al., 1997, JAS)

Source function is from δ-two approximation but intensity is computed in four-stream directions. Computation time is four times faster than δ-4 stream method.

Spherical SFC Emissivity $\left\langle \varepsilon \right\rangle = 2\int_0^1 \varepsilon(\mu)\mu\, d\mu$

Spherical SFC Albedo $\left\langle \rho \right\rangle = 1 - \left\langle \varepsilon \right\rangle$

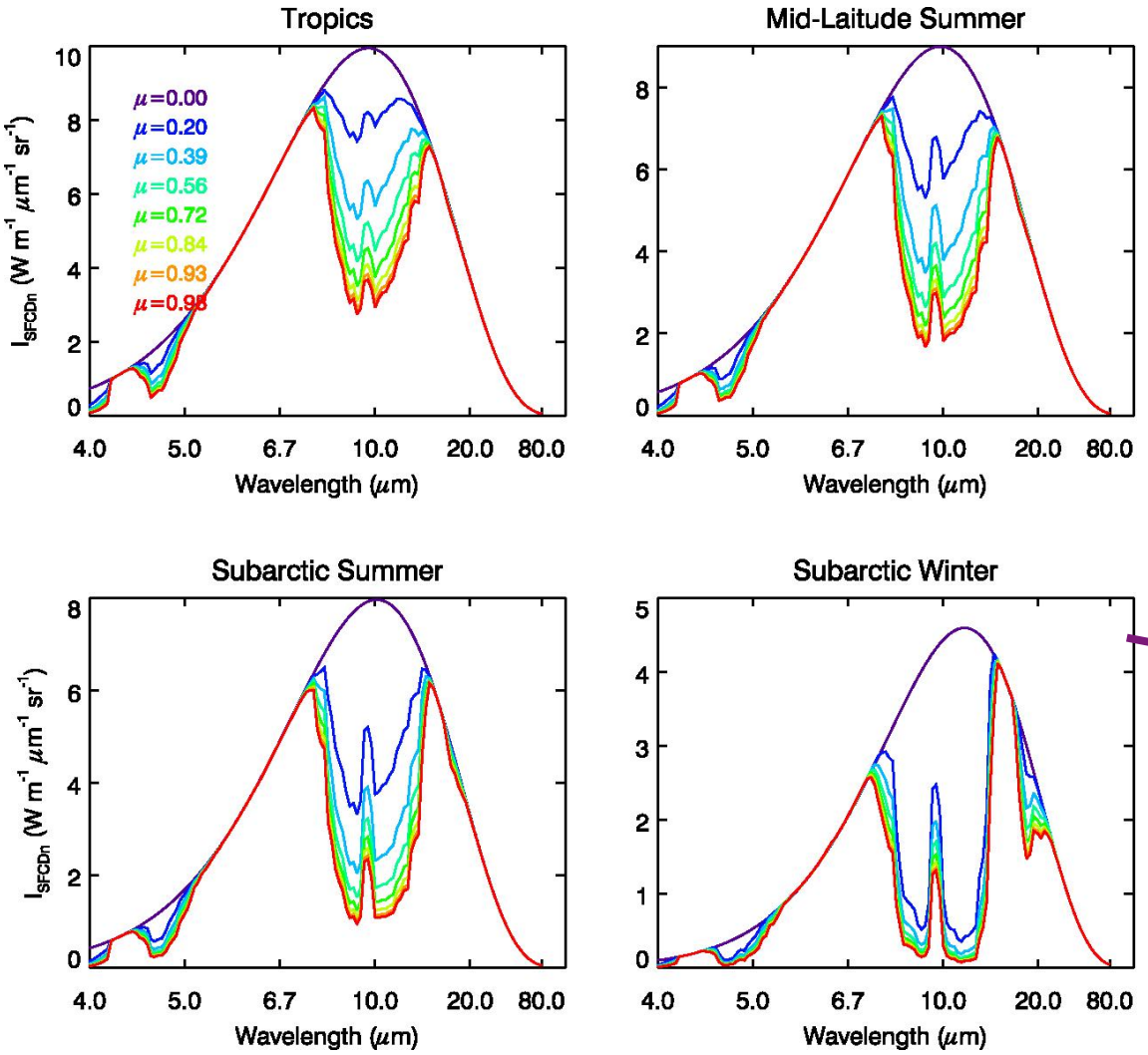
SFC Upward irradiance in Fu-Liou Model

Upward irradiance with no approximation

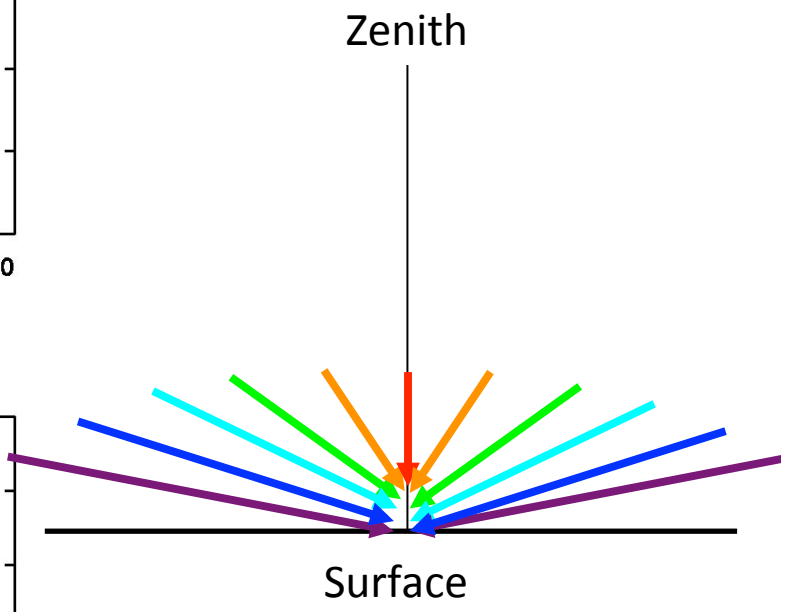
	Reflected	Emitted
$F_{Fu-Liou} =$	$\pi\left\langle \rho \right\rangle\left\langle I^- \right\rangle$	$+\,\pi\left\langle \varepsilon \right\rangle B(T_s)$
	$\Vert$	$\Vert$
$F =$	$\pi\left\langle \rho I^- \right\rangle$	$+\,\pi\left\langle \varepsilon \right\rangle B(T_s)$

If either ρ or I^- is independent of μ, $F_{\text{Fu-Liou}}$ and F are the same…but..

Anisotropic Downward SFC Incoming Radiance

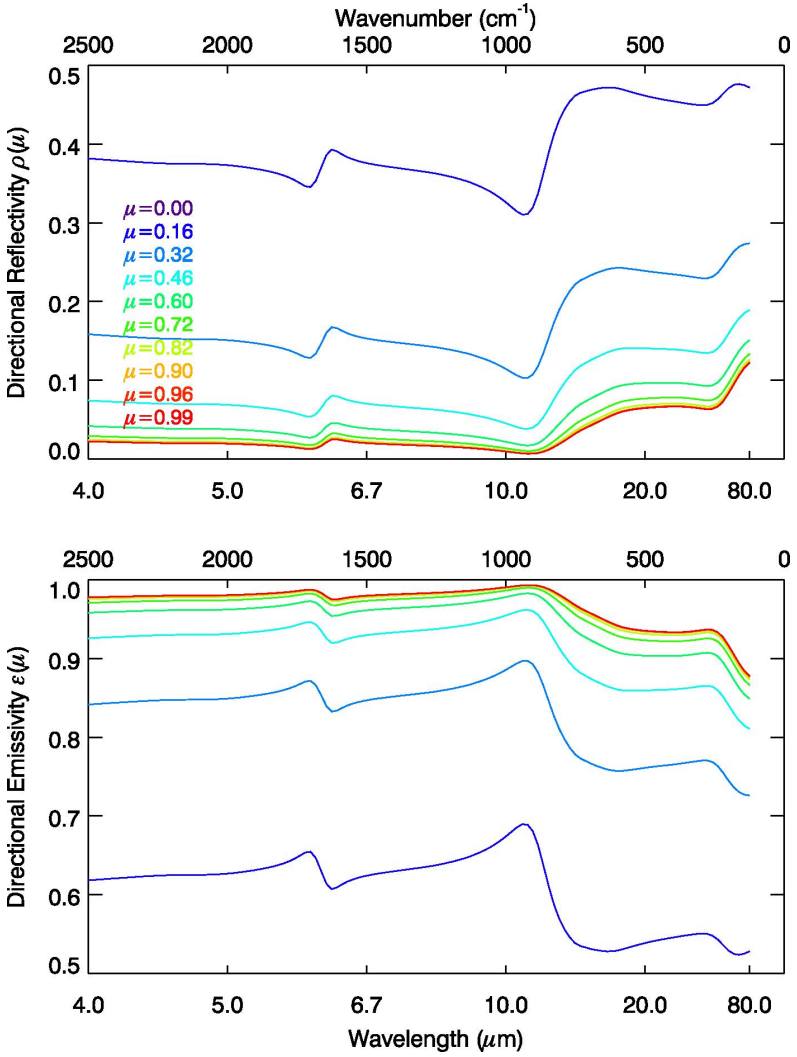


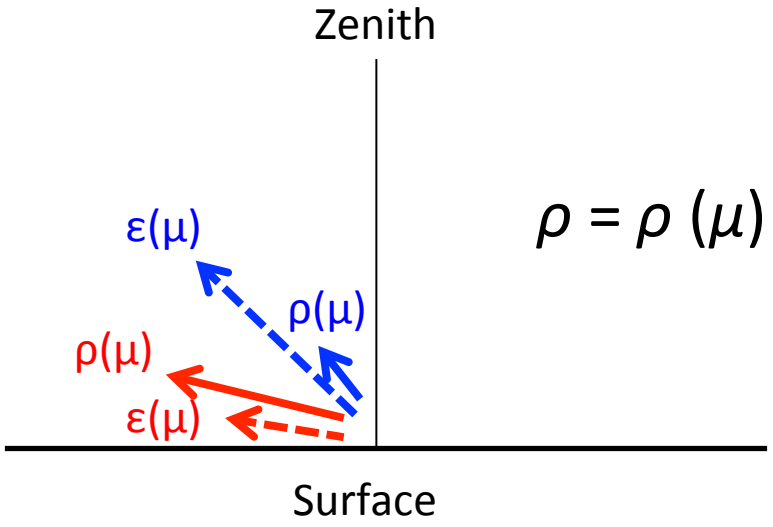
$I^{-} = I^{-}(\mu)$



As μ decreases (or θ increases), incoming radiance increases.

Directional Dependence of Smooth Ocean Emissivity





$\rho = \rho\,(\mu)$

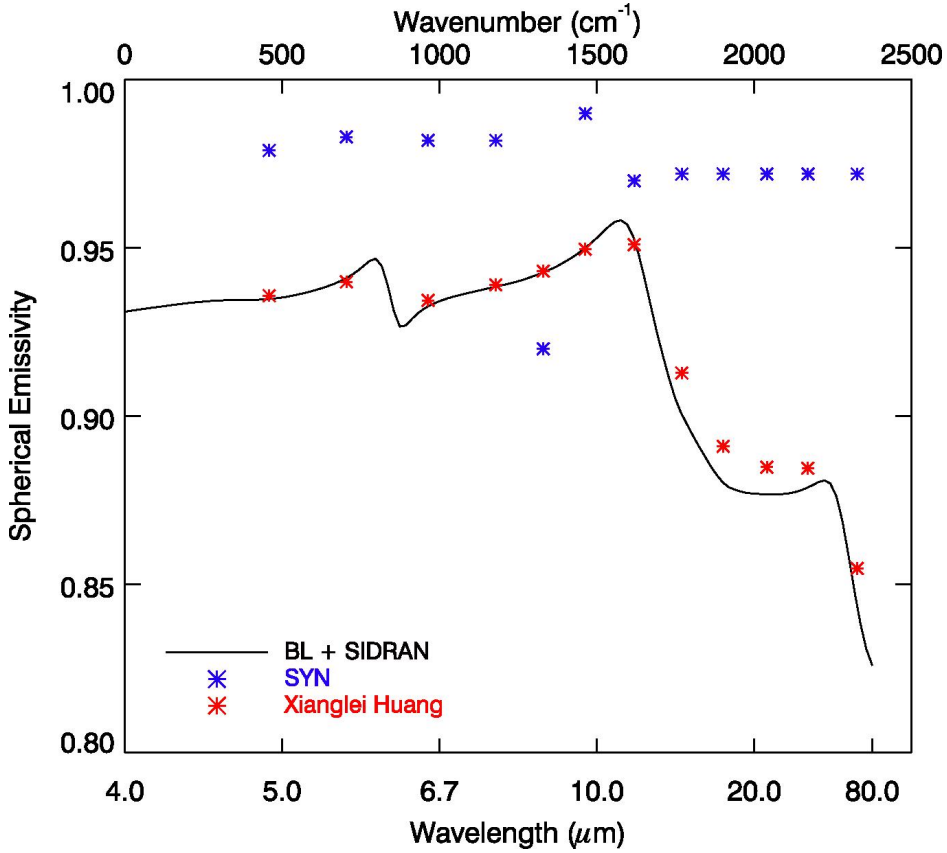
As outgoing zenith angle θ increases (or μ decreases), reflectance ρ(μ) increases and emissivity ε(μ) decreases.

$$\rho(\mu) + \varepsilon(\mu) = 1$$

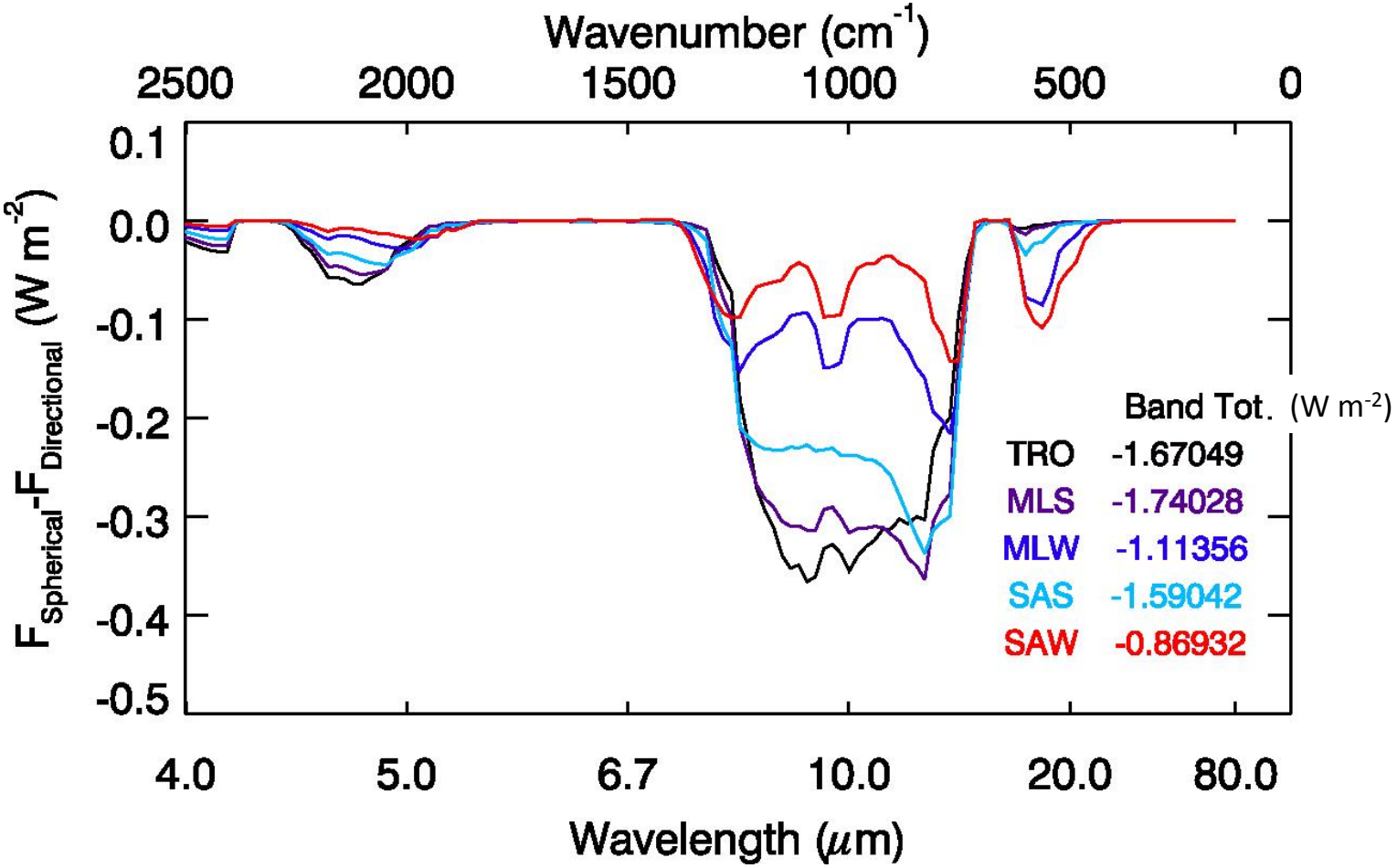
Ocean Directional Reflectivity/Emissivity Model

1. Fresnel Equations
2. Bertie and Lan (BL) (1996) complex water refractive index
3. Surface roughness effect by wind speed is considered using Sidran (1981); wind speed increases emissivity

Computed spherical emissivity by integrating Directional Emissivity



Bias in SFCUP Irradiances Occurred by Spherical Albedo



40-stream DISORT model is used for both cases.

Bias Correction of Irradiance Using Spherical Albedo

Reflected Emitted

SFC Upward irradiance From spherical albedo

$$F_{2str} = \langle\rho\rangle\langle I^-\rangle + \langle\varepsilon\rangle B(T_s)$$

$$\wedge \qquad\qquad =$$

SFC Upward irradiance From directional albedo

$$F = \langle\rho I^-\rangle + \langle\varepsilon\rangle B(T_s)$$

Correction Factor for Spherical Albedo

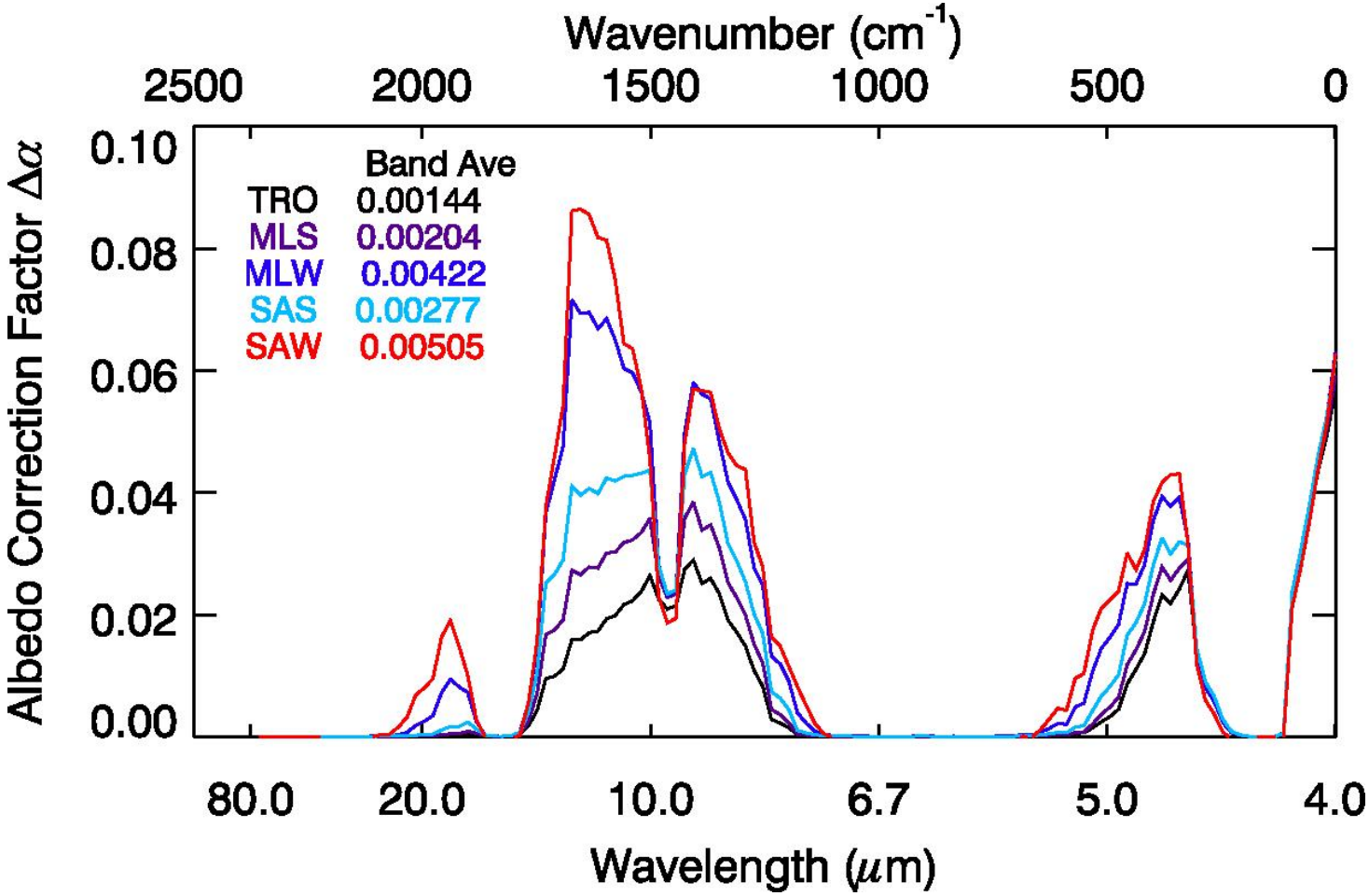
$$\left(\langle\rho\rangle + \Delta\langle\rho\rangle\right)\langle I^-\rangle = (\alpha + \Delta\alpha)\langle I^-\rangle = \langle\rho I^-\rangle, \quad \Delta\alpha \geq 0$$

$$\therefore \Delta\alpha = \frac{\langle\rho I^-\rangle - \langle\rho\rangle\langle I^-\rangle}{\langle I^-\rangle}$$

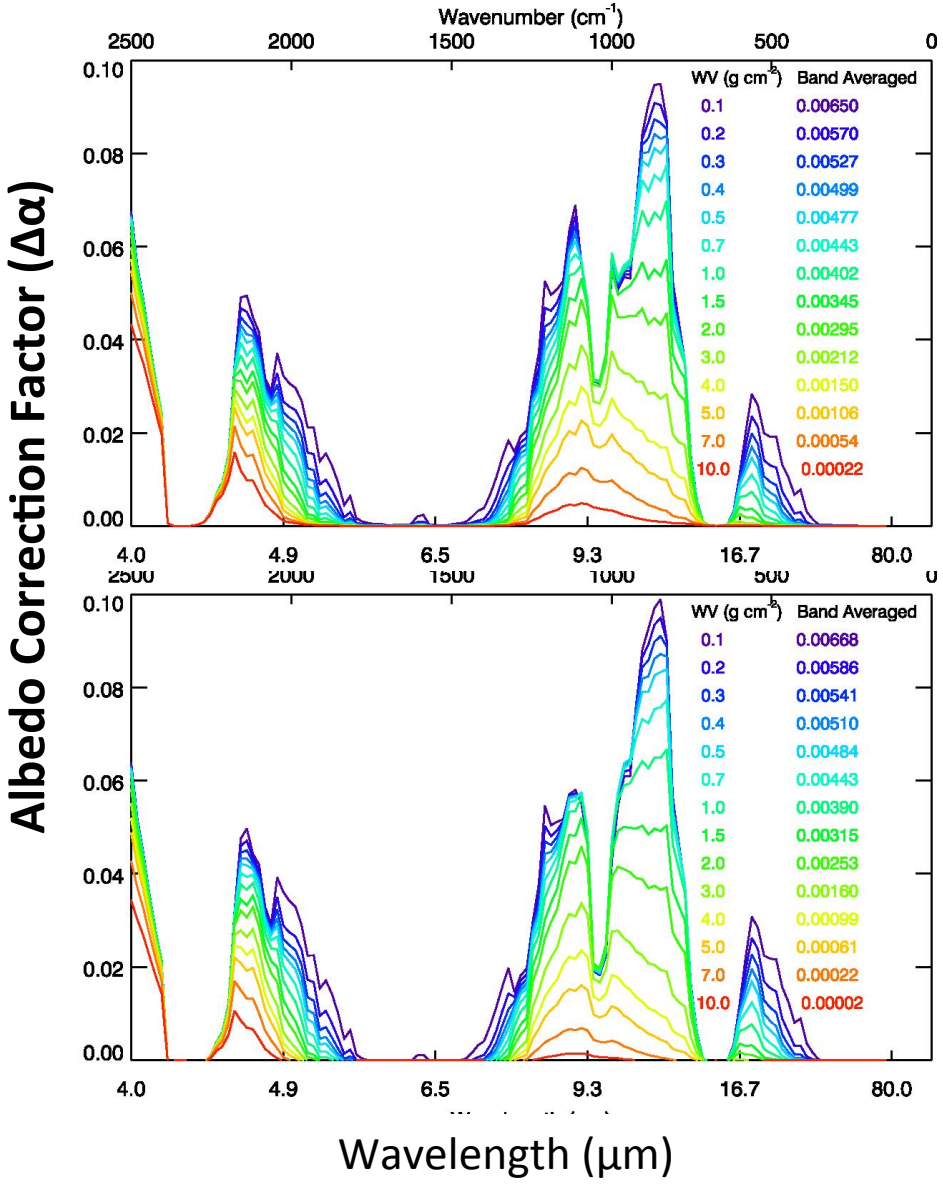
$$\Delta\langle\varepsilon\rangle = -\Delta\alpha = -\frac{\langle\varepsilon I^-\rangle - \langle\varepsilon\rangle\langle I^-\rangle}{\langle I^-\rangle}$$

$$\rho(\mu) + \varepsilon(\mu) = 1 \qquad \text{but} \qquad \langle\rho'\rangle + \langle\varepsilon\rangle \neq 1$$

Albedo Correction Factor for Standard Atmospheres



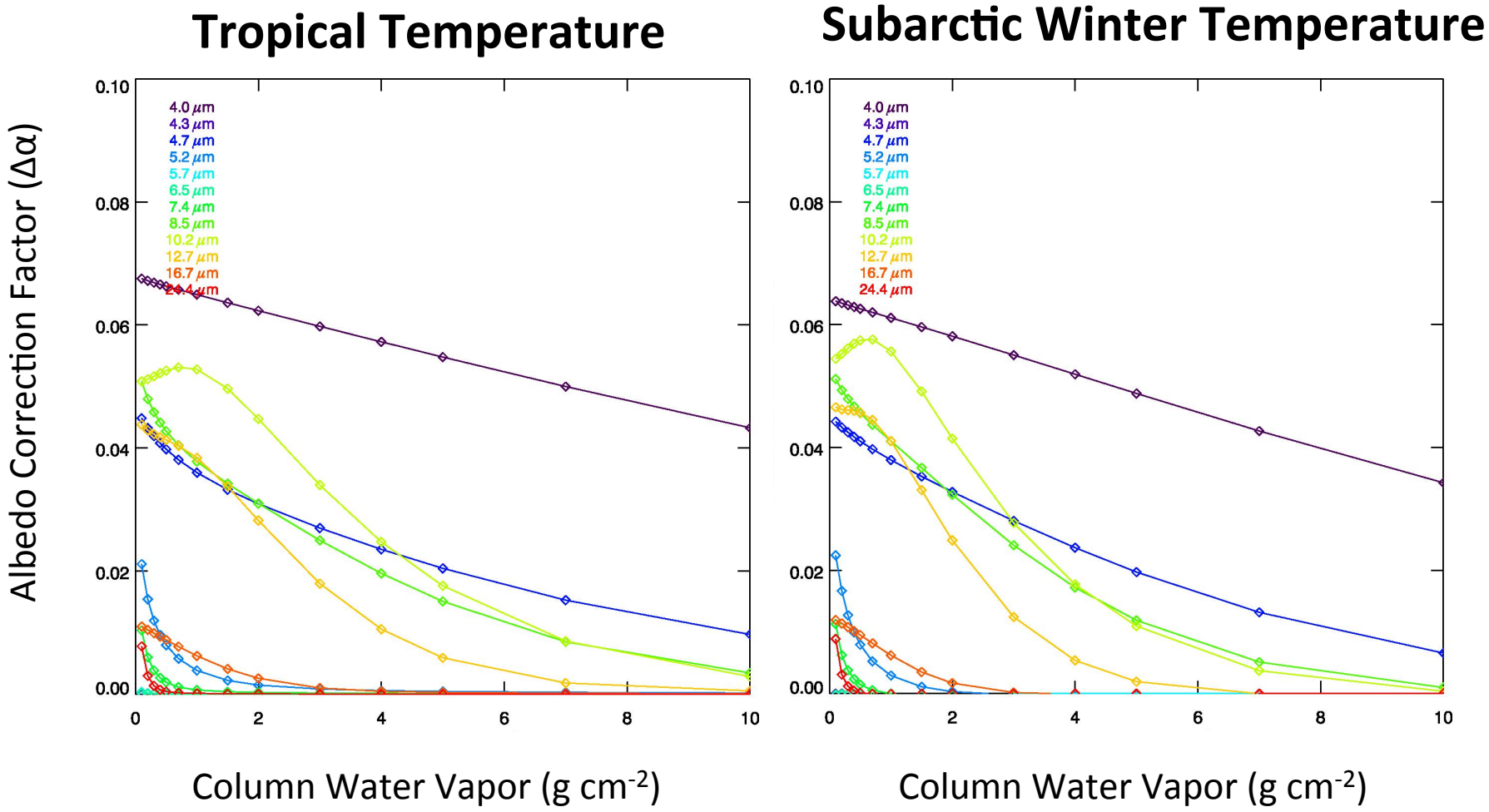
Albedo Correction Factor with WV Amount



Tropical Temperature with Different WVs

Subarctic Winter Temperature with Different WVs

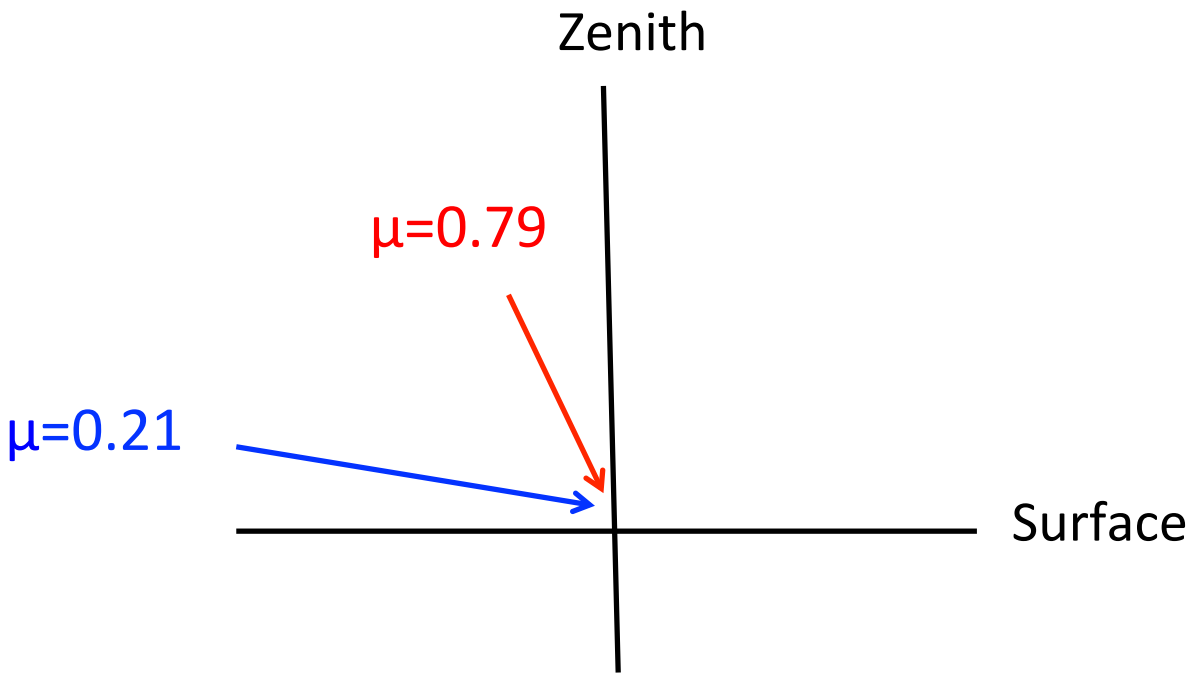
Albedo Correction Factor Δα with WV Amounts



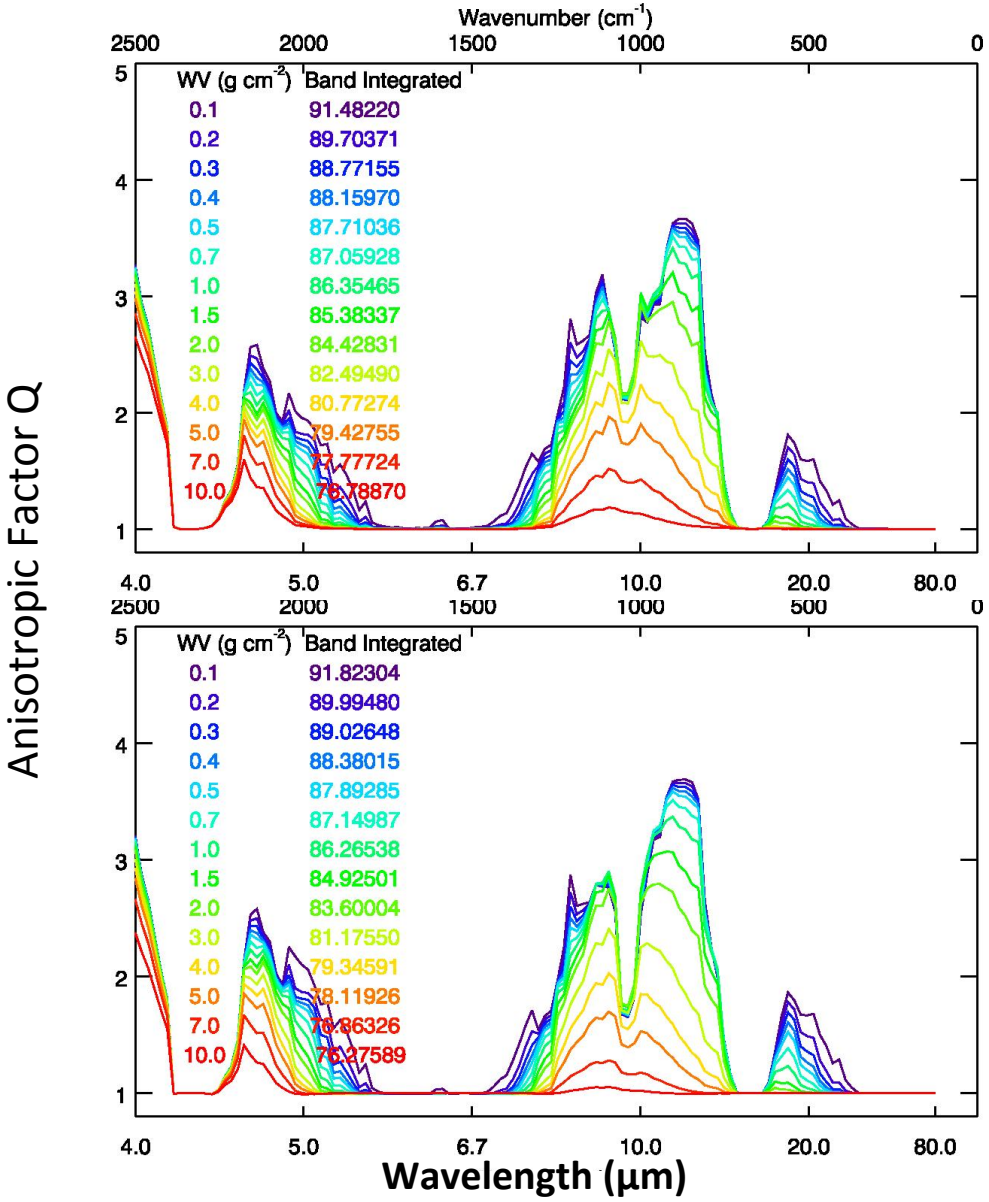
Anisotropic Factor Definition from FL Model Output

Anisotropy Factor in Downward Radiance by different incoming angle

$$Q = \frac{I^{-}(\mu = 0.21)}{I^{-}(\mu = 0.79)} \geq 1$$



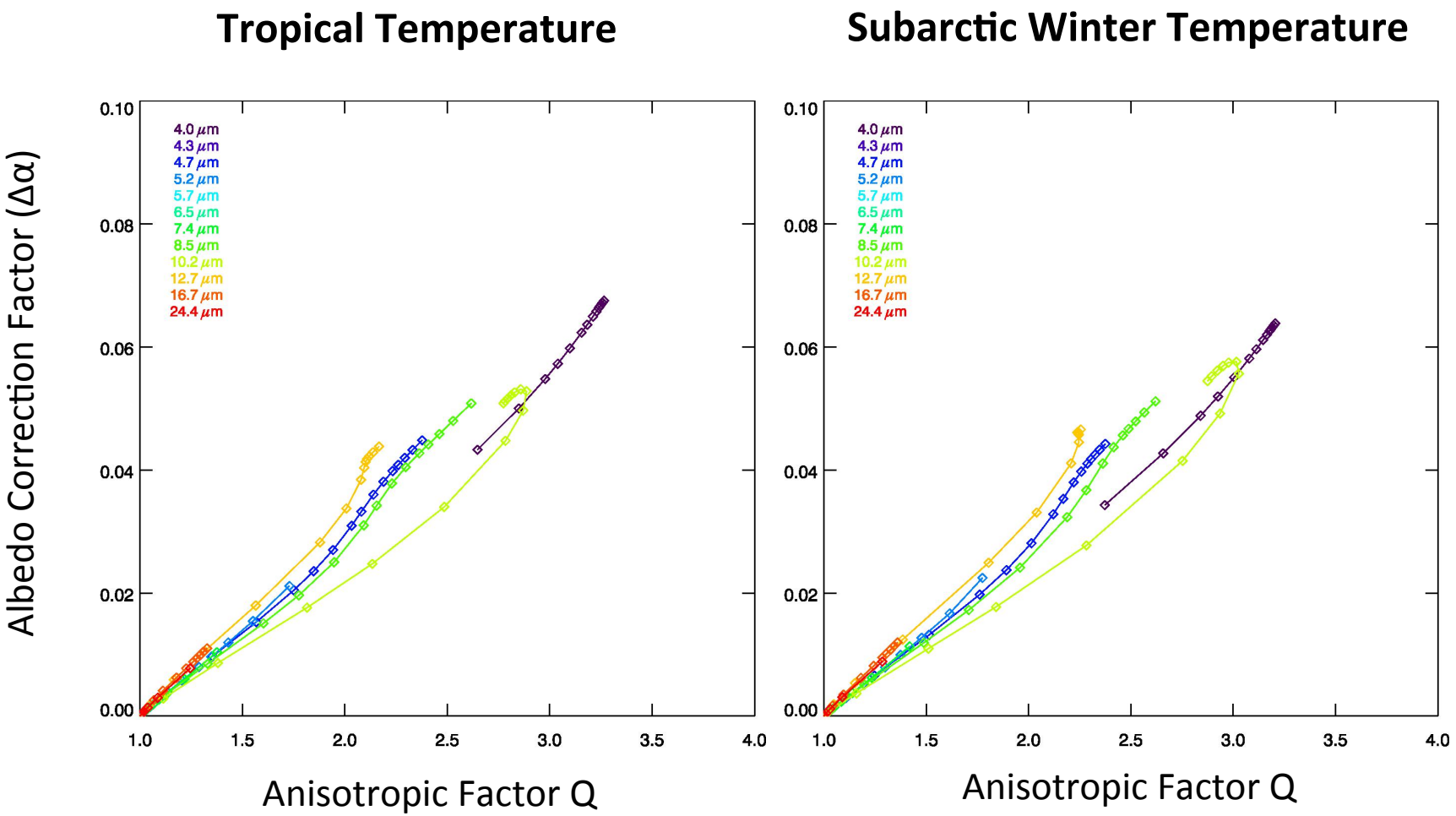
Anisotropic Factor (Q) with WV Amounts



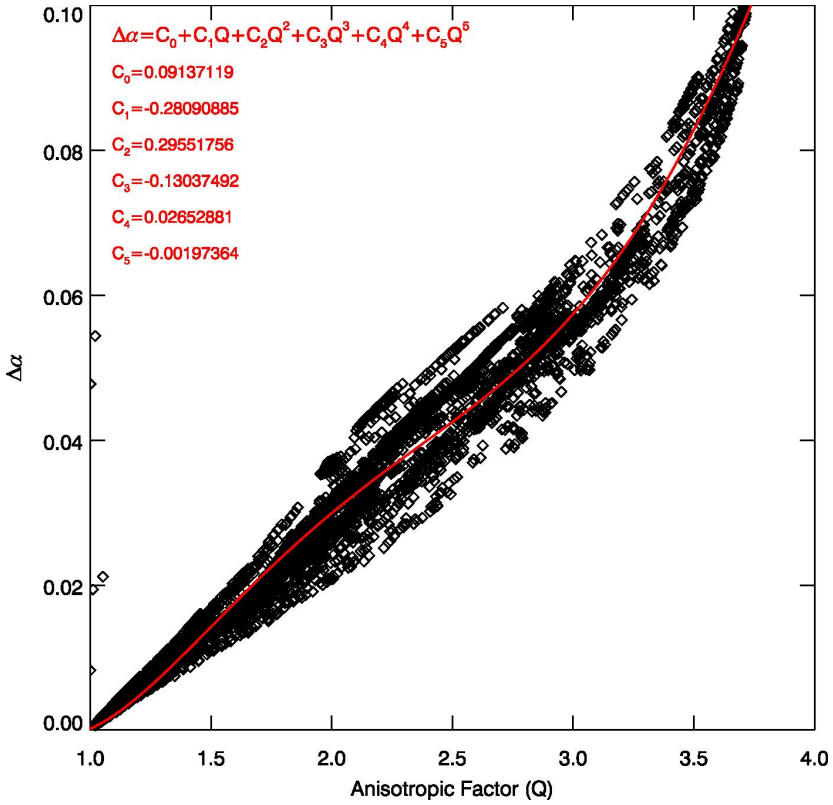
Tropical Temperature with Various WVs

Subarctic Winter Temperature with Various WVs

Albedo Correction Factor with Anisotropic Factor



Albedo Correction Factor for Various Temperatures and Humidity Profiles



By considering different moisture, temperature, and wavelength, universal albedo correction factor is obtained as a function of anisotropic factor Q.

$$\Delta\alpha = 0.09137119 - 0.28090885Q + 0.29551756\,Q^2 - 0.13037492\,Q^3 + 0.02652881\,Q^4 - 0.00197364\,Q^5$$

$$Q = I^-(\mu=0.21) / I^-(\mu=0.79)$$

Emissivity Sensitivity Using Fu-Liou RTM

SAW	**Emissivity**	**Albedo**	**Sfc LW Up (W m^{-2})**	
Ed4	0.9722	0.0278	245.6	
X.Huang	0.9184 (-0.0538)	0.0816 (+0.0538)	243.6 (-2.0)	+1.2
X.Huang+Cor	0.9184 (-0.0538)	0.0935 (+0.0657)	244.8 (-0.8)	
SAS				
Ed4	0.9722	0.0278	381.9	
X.Huang	0.9184 (-0.0538)	0.0816 (+0.0538)	380.1 (-0.8)	+1.4
X.Huang+Cor	0.9184 (-0.0538)	0.0926 (+0.0648)	382.5 (+0.6)	
MLW				
Ed4	0.9722	0.0278	307.6	
X.Huang	0.9184 (-0.0538)	0.0816 (+0.0538)	305.6 (-2.0)	+0.9
X.Huang+Cor	0.9184 (-0.0538)	0.0902 (+0.0624)	306.5 (-1.1)	
MLS				
Ed4	0.9722	0.0278	421.1	
X.Huang	0.9184 (-0.0538)	0.0816 (+0.0538)	419.7 (-1.4)	+1.8
X.Huang+Cor	0.9184 (-0.0538)	0.0886 (+0.0608)	421.5 (+0.4)	
TROP				
Ed4	0.9722	0.0278	457.0	
X.Huang	0.9184 (-0.0538)	0.0816	455.9 (-1.1)	+1.6
X.Huang+Cor	0.9184 (-0.0538)	0.0869	457.5 (0.5)	

Summary and Conclusions

- SYN uses delta-two and four stream combination method, ignoring directional effects of incoming radiance and ocean reflectivity.
- The use of spherical reflectivity and emissivity causes negative biases around 1 − 2 W m^{-2}, and the biases increase with surface temperature and decrease with humidity.
- To remove the negative biases, we implement a correction factor for spherical albedo. Larger albedo correction factor is needed for drier atmosphere.
- Compared to water vapor amount itself, anisotropic factor defined from Fu-Liou model output explains albedo correction better with a higher correction.
- New ocean directional emissivity decreases and so does upward SFC irradiance by 1 − 2 W m^{-2}. Moreover albedo correction factor increases upward SFC irradiances by 1 − 2 W m^{-2}. As a result, total changes in SYN irradiance are order of ±1 W m^{-2}.