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

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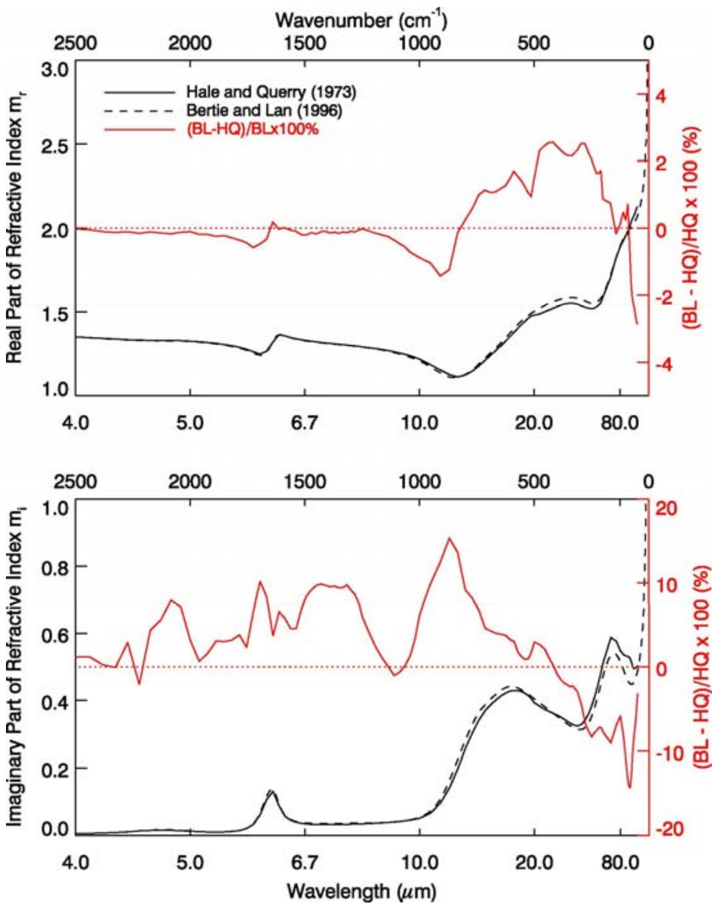
Objectives

- Update water refractive index for SYN directional emissivity model
- Examine directional effects in infrared transfer in 2-stream approximation
- Implement a correction factor for spherical emissivity/albedo for 2-stream approximation
- Examine dependence of correction factor on water vapor and wavelength
- Parameterization of directional effects in 2-stream model
- Application to SYN

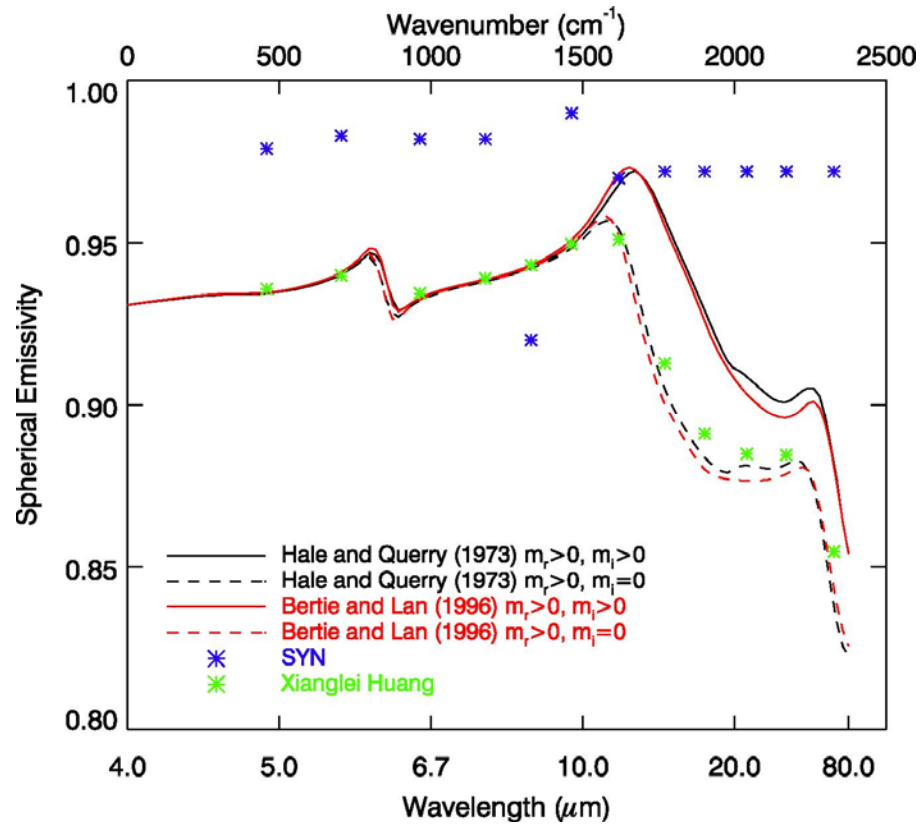
Updates of Refractive Indices of Water

1. Taking into account imaginary part of refractive index
2. Replacing Hale and Querry (HQ) (1973) with Bertie and Lan (BL) (1996), while latter is based on more improved computation and experiments in a higher resolution

HQ and BL Refractive Index



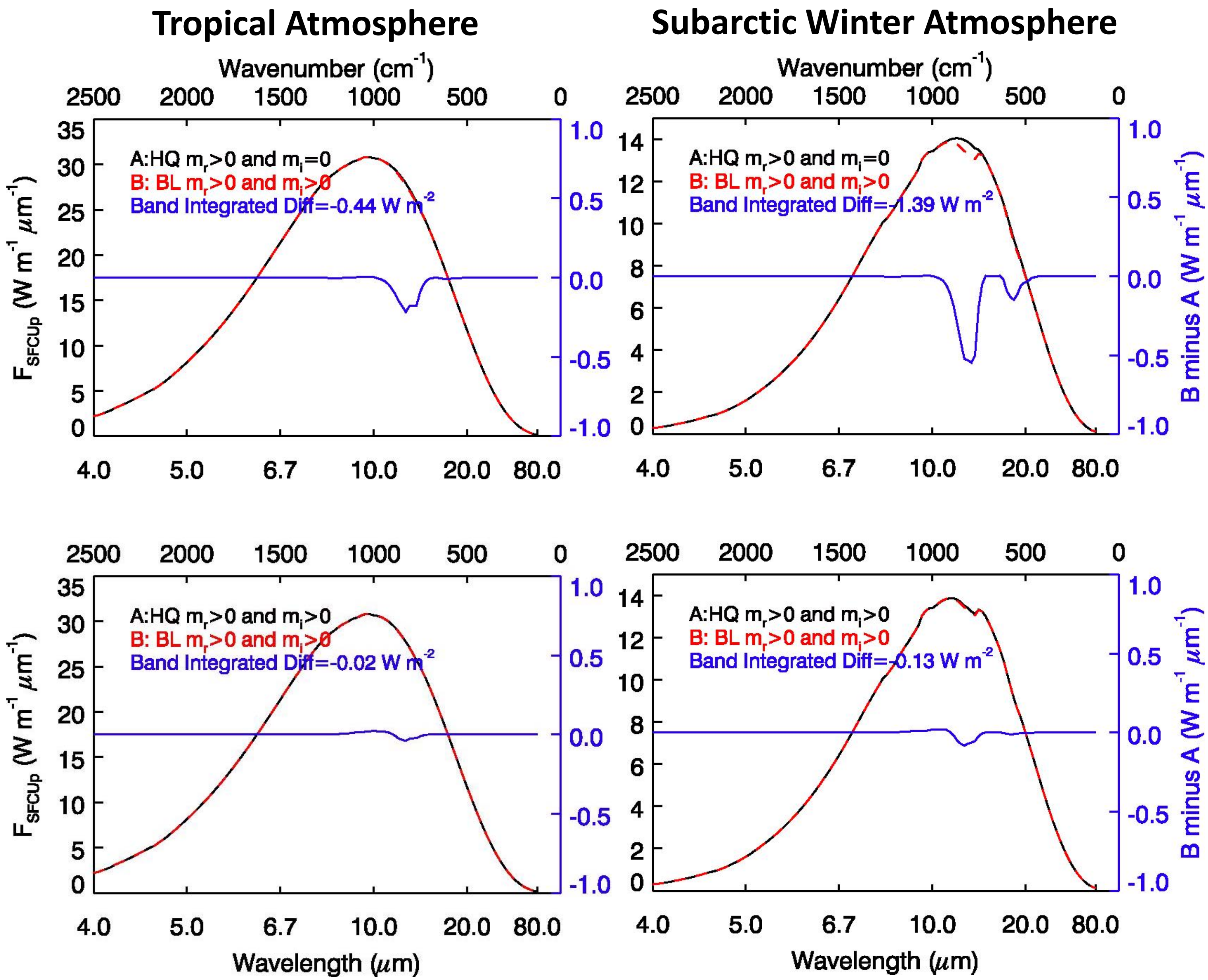
Spherical Emissivity



Impact of Refractivity Index on SFC Upward Irradiance

Implementing m_i decreases SFCUP irradiance.

Differences between two refractive index data (HQ and BL) are minor.



Surface Upward Irradiance (Azimuthally Independent)

Spherical Averaging

$$\langle x \rangle = 2\int_0^1 x(\mu)\mu\, d\mu, \qquad \mu = \cos\theta_0$$

SFC Upward radiance with outgoing direction μ

Directional Emissivity with outgoing angle 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'

SFC Upward irradiance

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

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

Directional Reflectivity

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

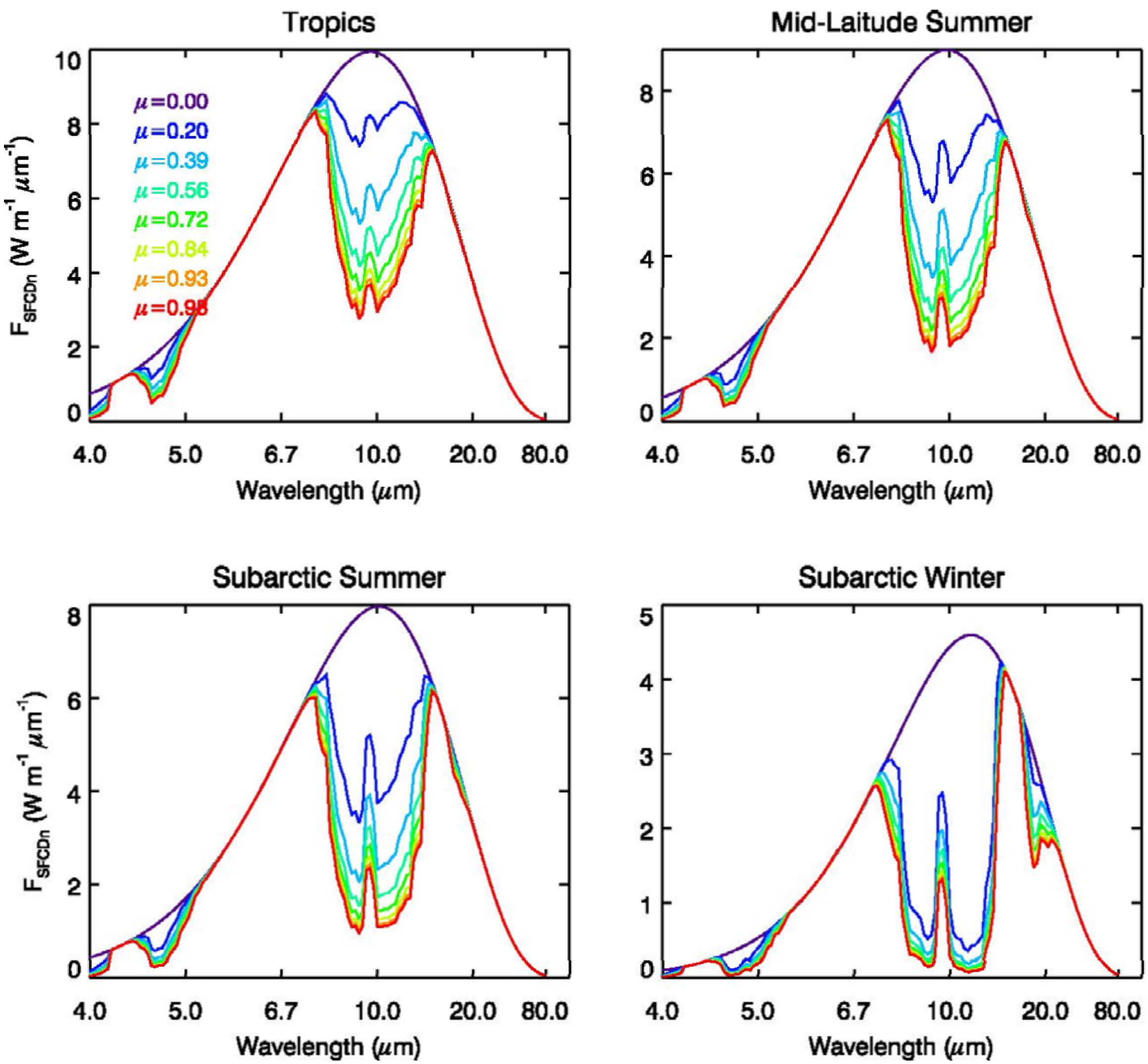
$$= 2\pi \int_0^1 I^-(\mu')\rho(\mu')\mu' d\mu' + 2\pi \int_0^1 \varepsilon(\mu) B(T_s)\mu\, d\mu$$

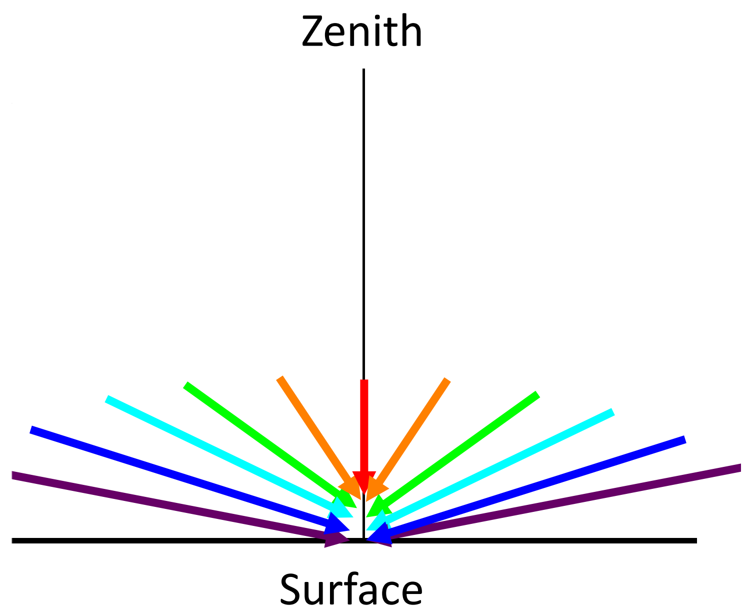
$$= \pi\left\{\left\langle \rho I^- \right\rangle + \left\langle \varepsilon \right\rangle B(T_s)\right\} = \pi\left\{\left\langle I^- \right\rangle - \left\langle \varepsilon I^- \right\rangle + \left\langle \varepsilon \right\rangle B(T_s)\right\}$$

Energy Conservation for opaque ocean (*T*=0) and Kirchoff's Law

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

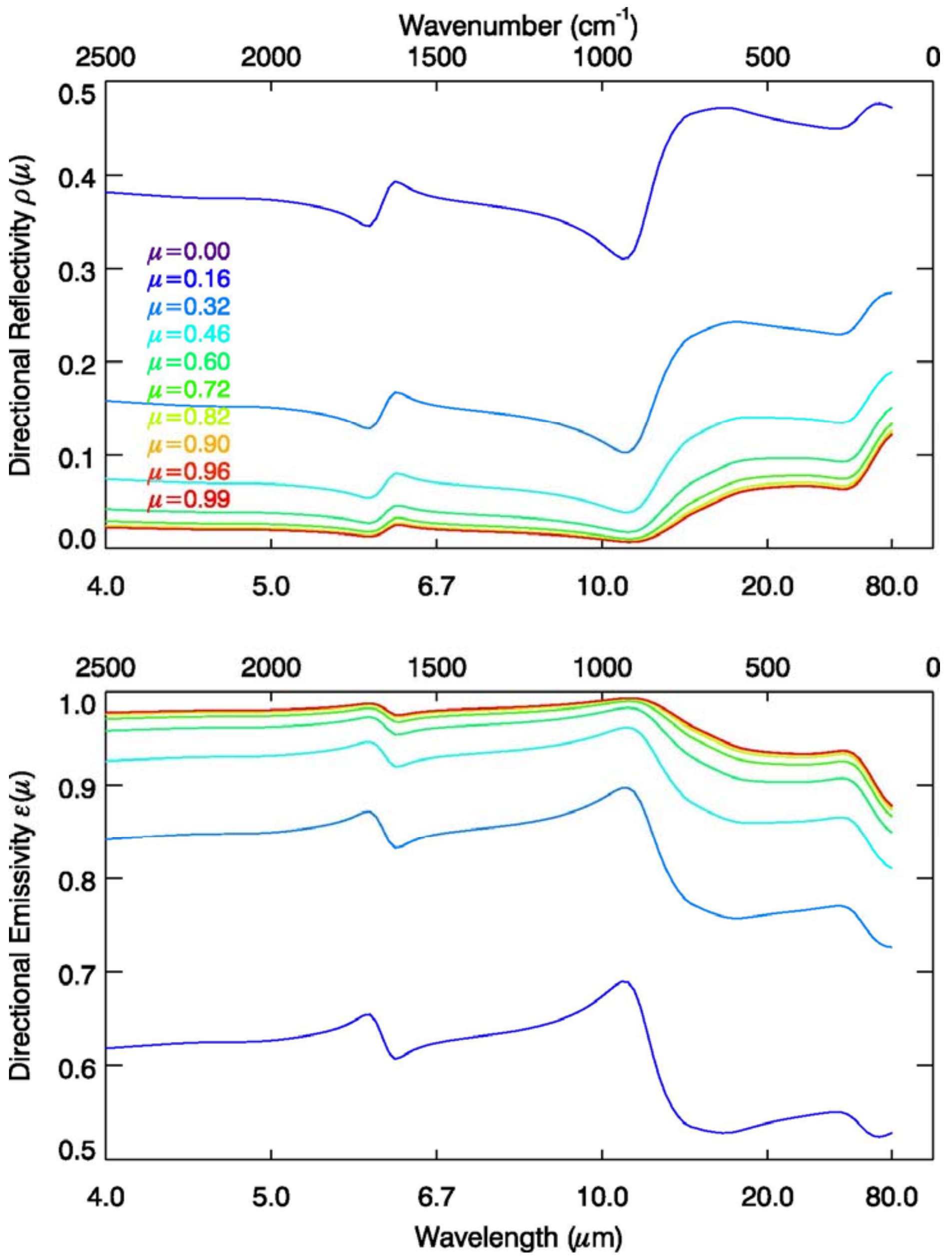
Anisotropy of Infrared Downward Radiance



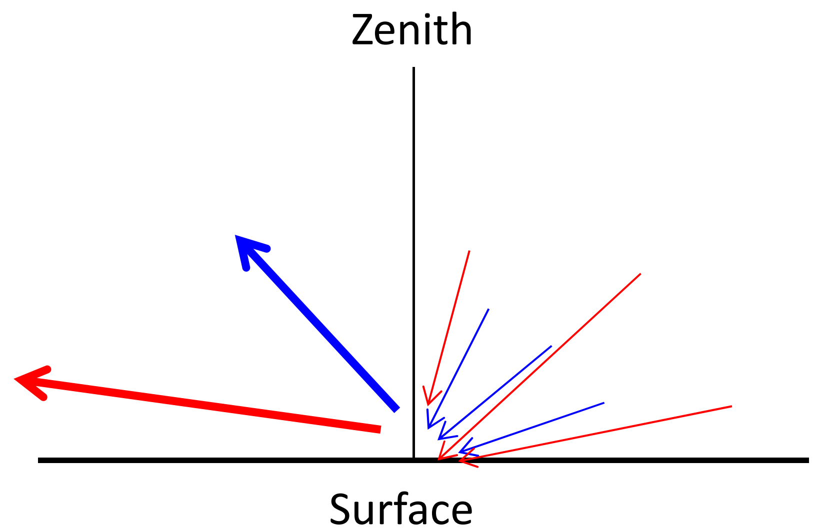


As μ increases (or θ decreases), F_{SFCDN} decreases.

Anisotropy of Ocean Reflectivity and Emissivity



$$F_{reflected} = 2\pi \int_0^1 \rho(\mu) I^-(\mu)\mu d\mu = \left\langle \rho I^- \right\rangle$$



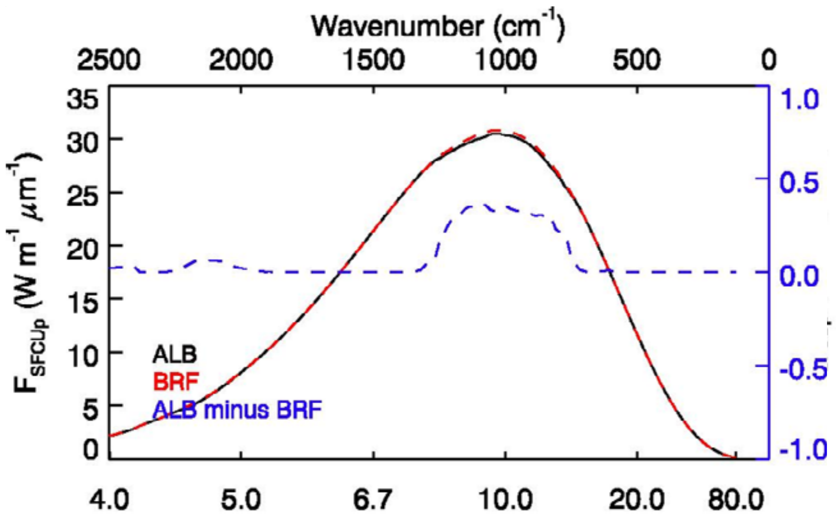
As outgoing zenith angle θ increases (or μ decreases), reflectance ρ(μ) increases and emissivity ε(μ) decreases.

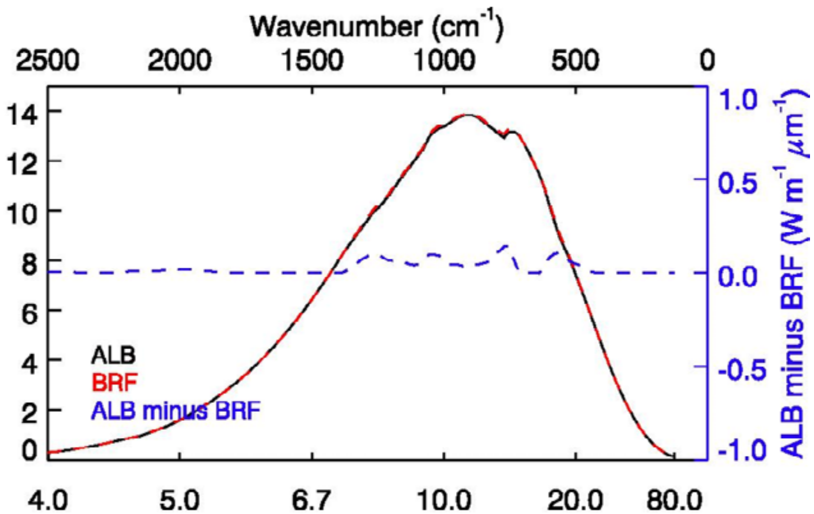
$$\rho(\mu) + \varepsilon(\mu) = 1$$

SFCUP Irradiances from Spherical and Directional Albedo

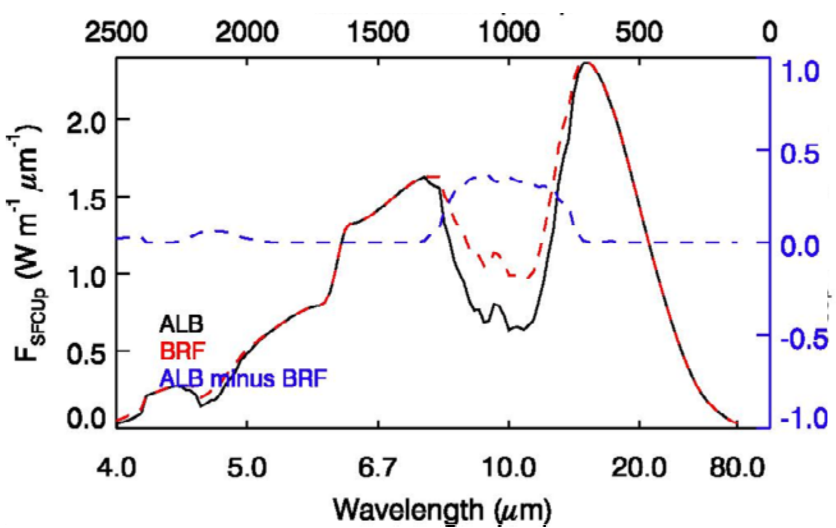
Tropical Atmosphere | **Subarctic Winter Atmosphere**

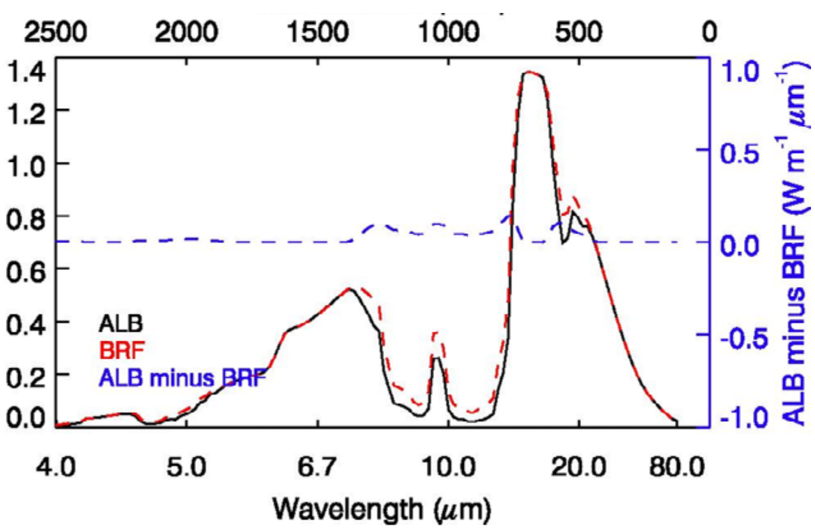
Emitted + Reflected SFCUP





Reflected SFCUP





Surface Upward Irradiance in Two-Stream Approximation

Spherical Averaging

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

Spherical SFC Emissivity

$$\langle \varepsilon \rangle = 2\int_0^1 \varepsilon(\mu)\mu \, d\mu$$

Spherical SFC Albedo

$$\alpha = 2\int_0^1 \rho(\mu)\mu d\mu = \langle \rho \rangle = 1 - \langle \varepsilon \rangle$$

SFC Upward irradiance
in 2-stream approximation

$$\begin{aligned} F_{2str} &= \pi \langle \rho \rangle \langle I^- \rangle + \pi \langle \varepsilon \rangle B(T_s) \\ &= \pi\alpha \langle I^- \rangle + \pi \langle \varepsilon \rangle B(T_s) \end{aligned}$$

Reflected Irradiance Between Two and Multiple Stream Approx

	Reflected		Emitted
SFC Upward irradiance in 2-stream Appox	$F_{2str} = \alpha\left\langle I^- \right\rangle$	$+$	$\left\langle \varepsilon \right\rangle B(T_s)$
	$\wedge$		$=$
SFC Upward irradiance In multiple streams	$F = \left\langle \rho I^- \right\rangle$	$+$	$\left\langle \varepsilon \right\rangle B(T_s)$

Correction Factor for Spherical Albedo

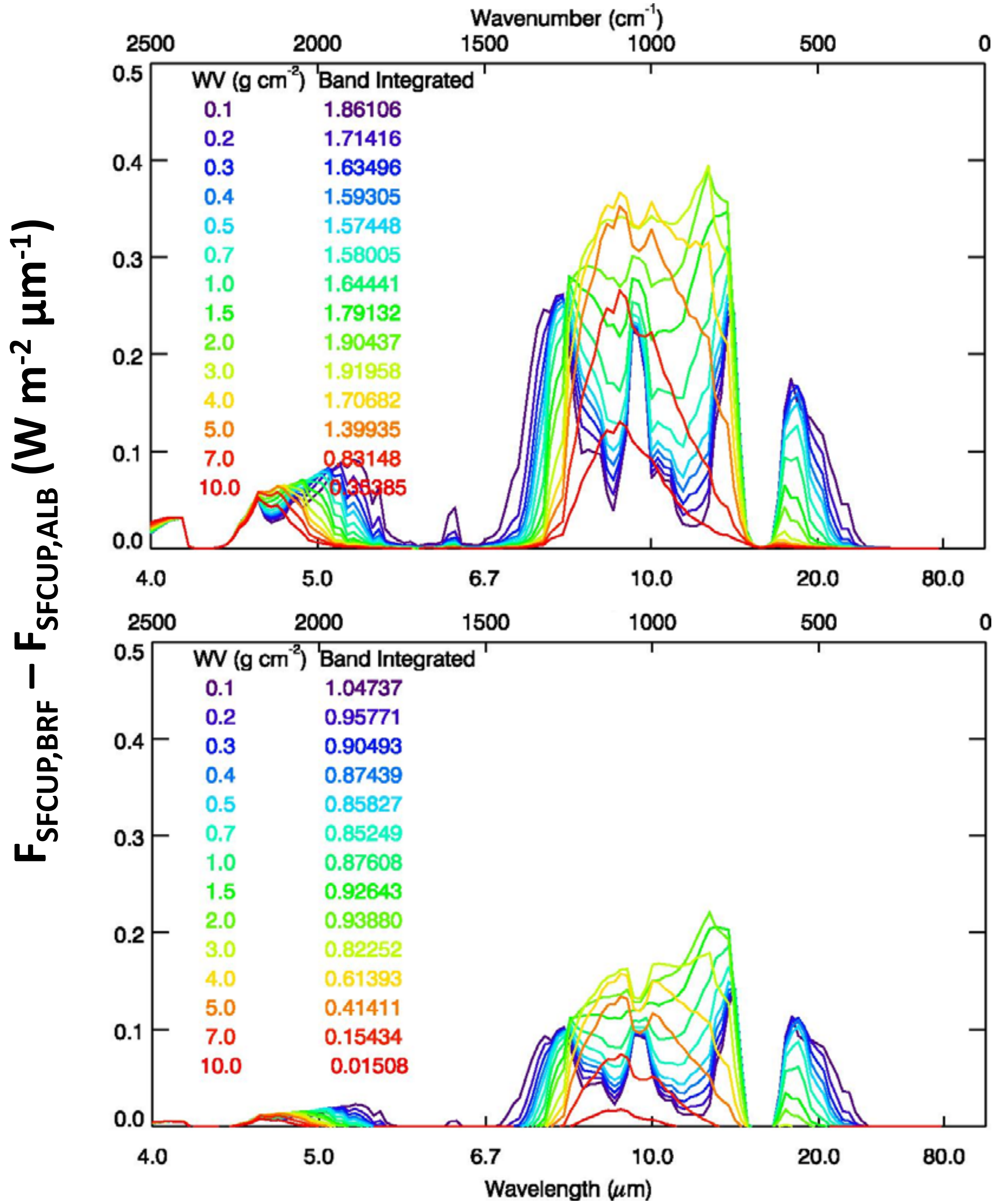
$$(\alpha + \Delta\alpha)\left\langle I^- \right\rangle = \left\langle \rho I^- \right\rangle$$

$$\therefore \Delta\alpha = \frac{\left\langle \rho I^- \right\rangle - \alpha\left\langle I^- \right\rangle}{\left\langle I^- \right\rangle} = \quad \text{or} \quad \Delta\varepsilon = -\Delta\alpha = \frac{\left\langle \varepsilon I^- \right\rangle - \left\langle \varepsilon \right\rangle\left\langle I^- \right\rangle}{\left\langle I^- \right\rangle}$$

SFCUP Irradiances from Spherical and Directional Albedo

Tropical Temperature with Different WVs

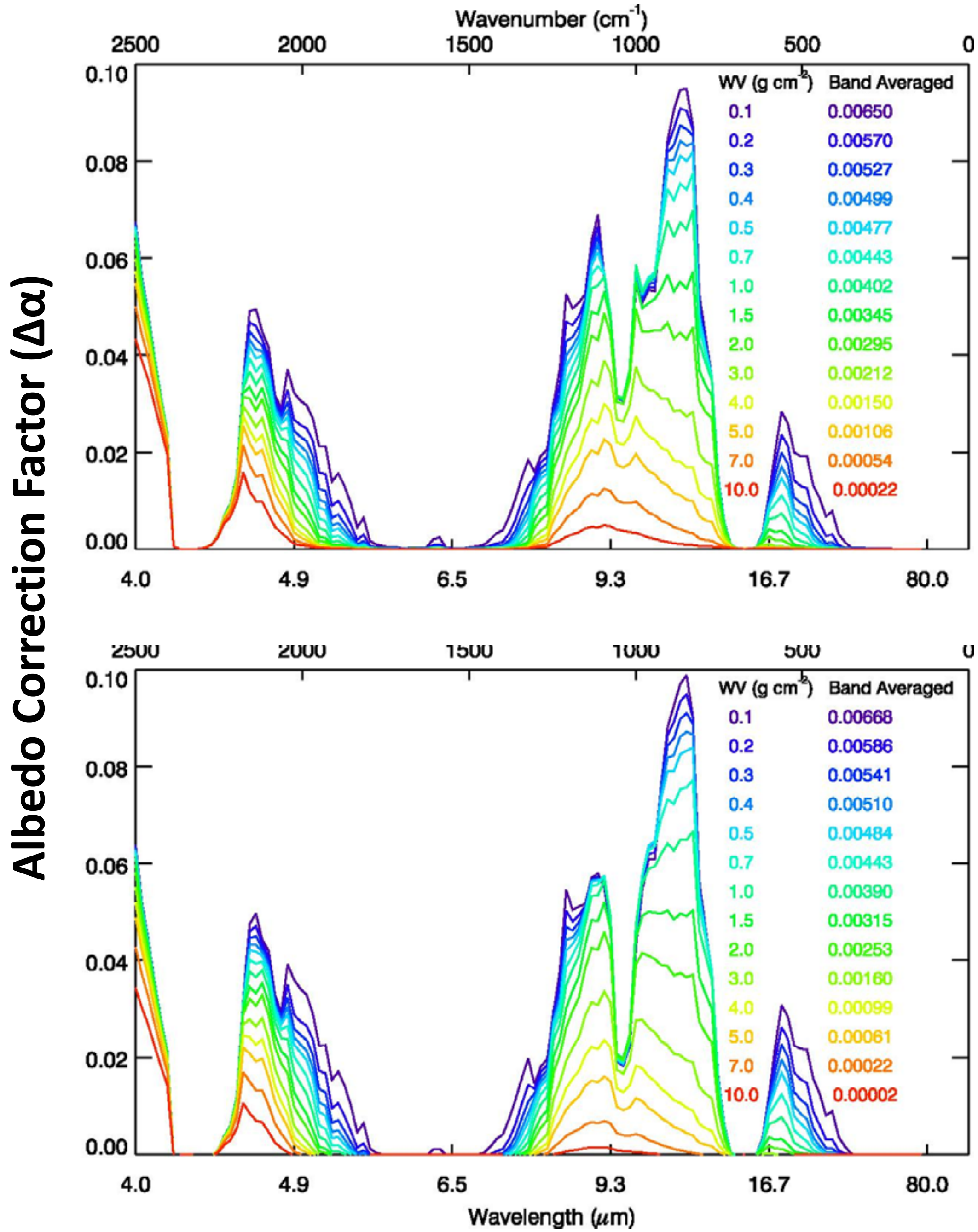
Subarctic Winter Temperature with Different WVs



Albedo Correction Factor as a Function of WV Amount

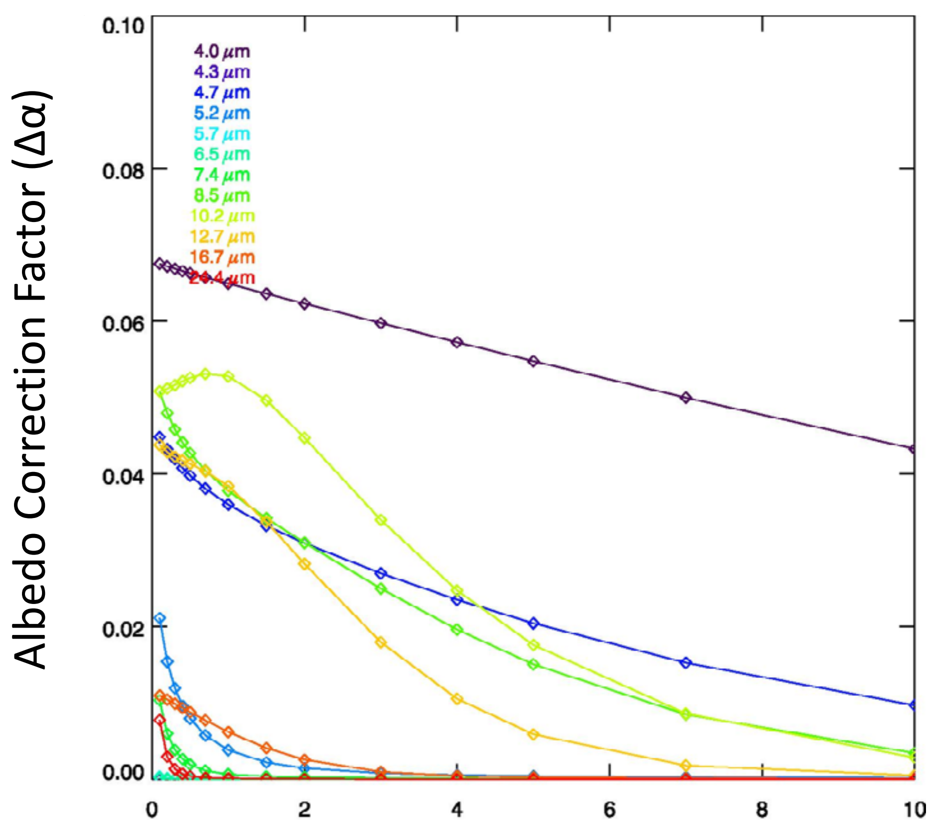
Tropical Temperature with Different WVs

Subarctic Winter Temperature with Different WVs



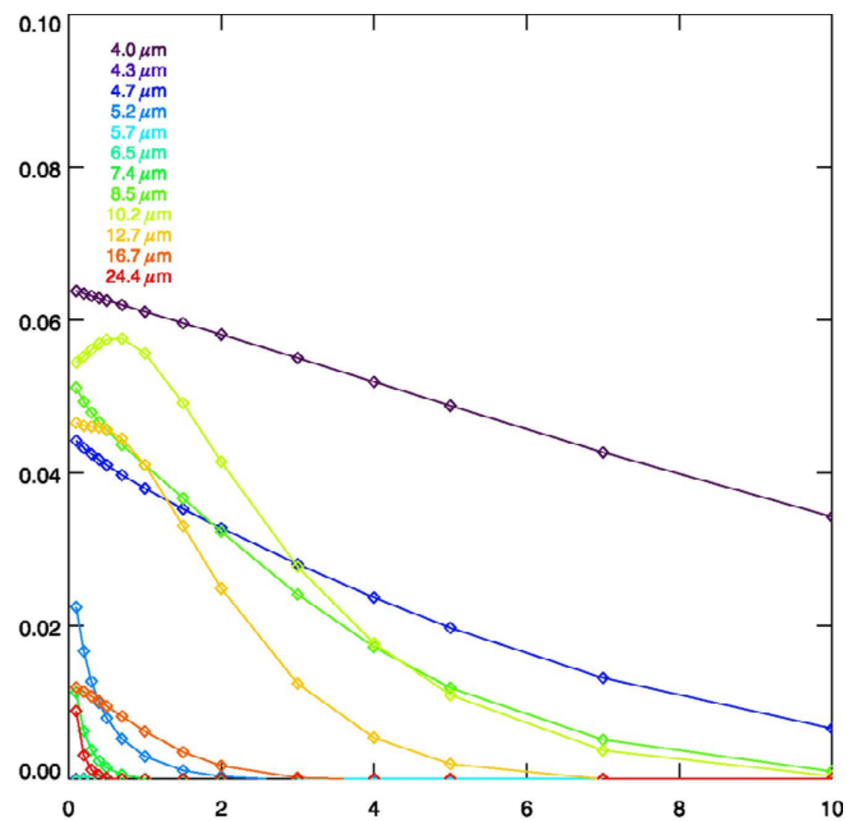
“Water Vapor” vs “Albedo Correction Factor Δα”

Tropical Temperature



Water Vapor (g cm^{-2})

Subarctic Winter Temperature



Water Vapor (g cm^{-2})

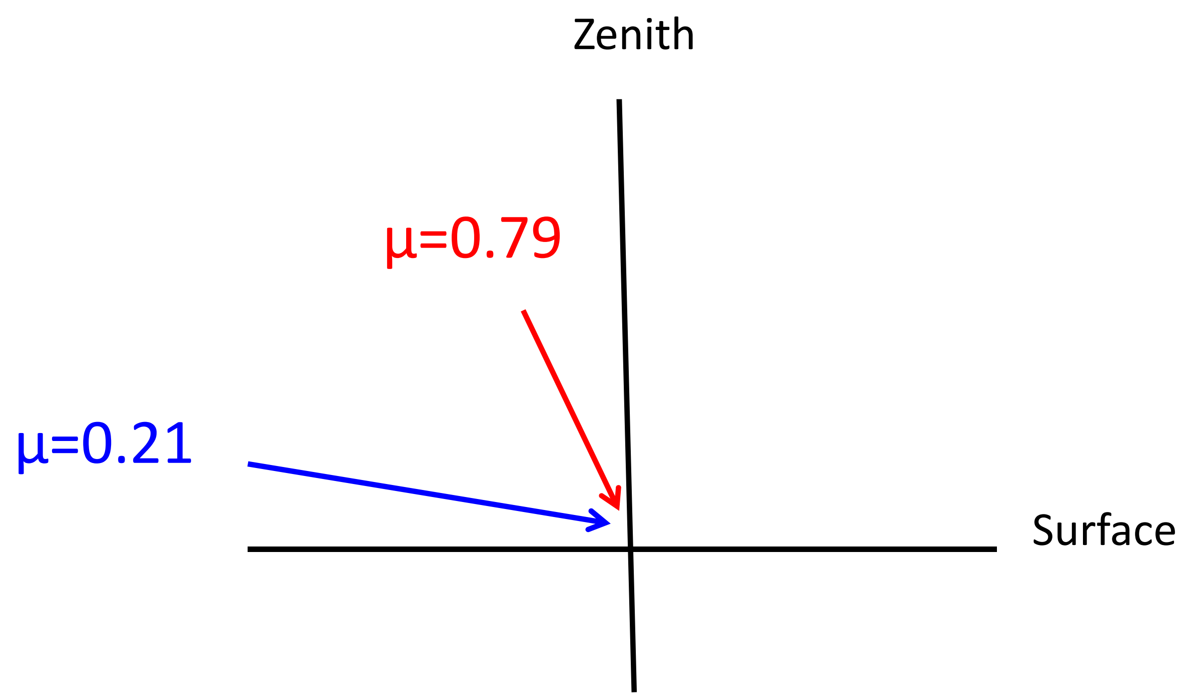
Drier atmosphere needs larger correction factor. But the relationship varies with wavelength because of different water vapor absorptivity.

Anisotropic Factor from Two Stream Model Output

Anisotropy Factor in Downward Radiance by different incoming angle

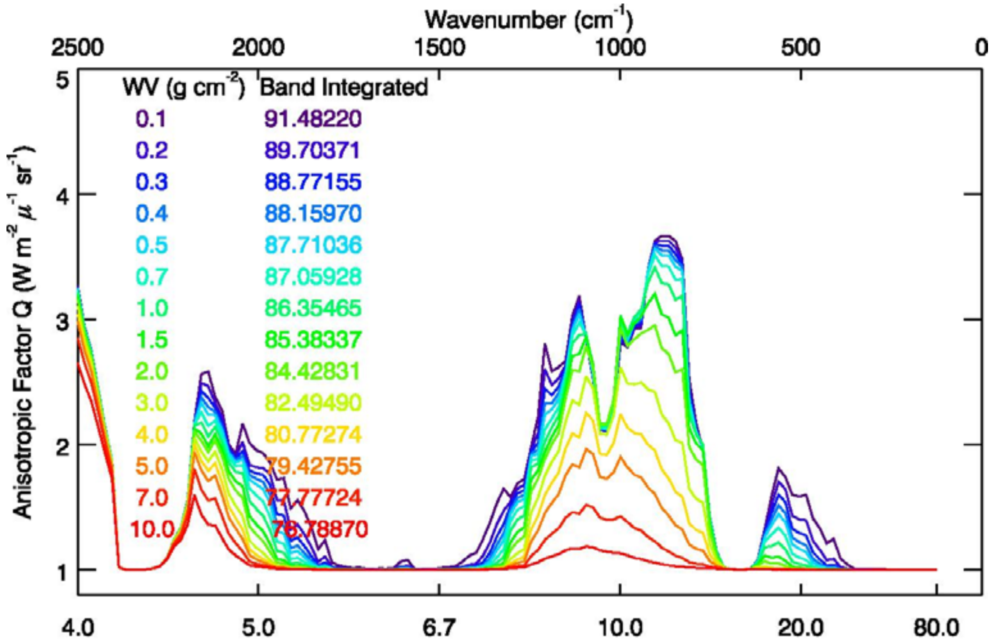
$$Q = \frac{I^{-}(\mu = 0.21)}{I^{-}(\mu = 0.79)}$$

Q ≥ 1 and Q decreases with water vapor amount.

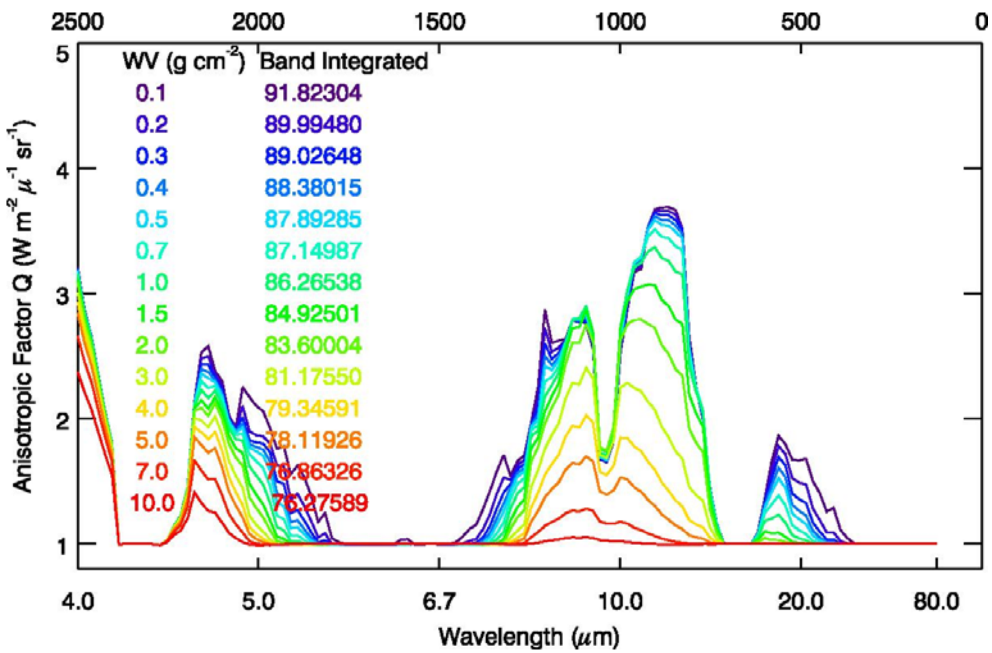


Albedo Correction Factor as a Function of WV Amount

Tropical Temperature



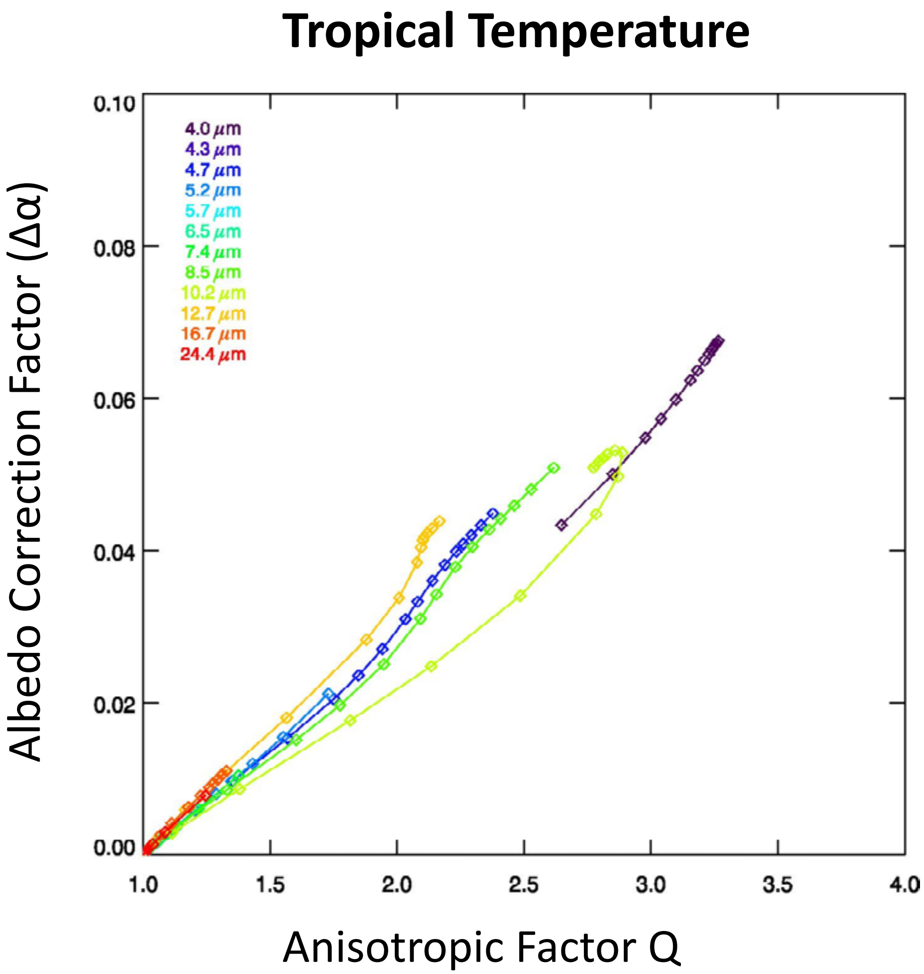
Subarctic Winter Temperature

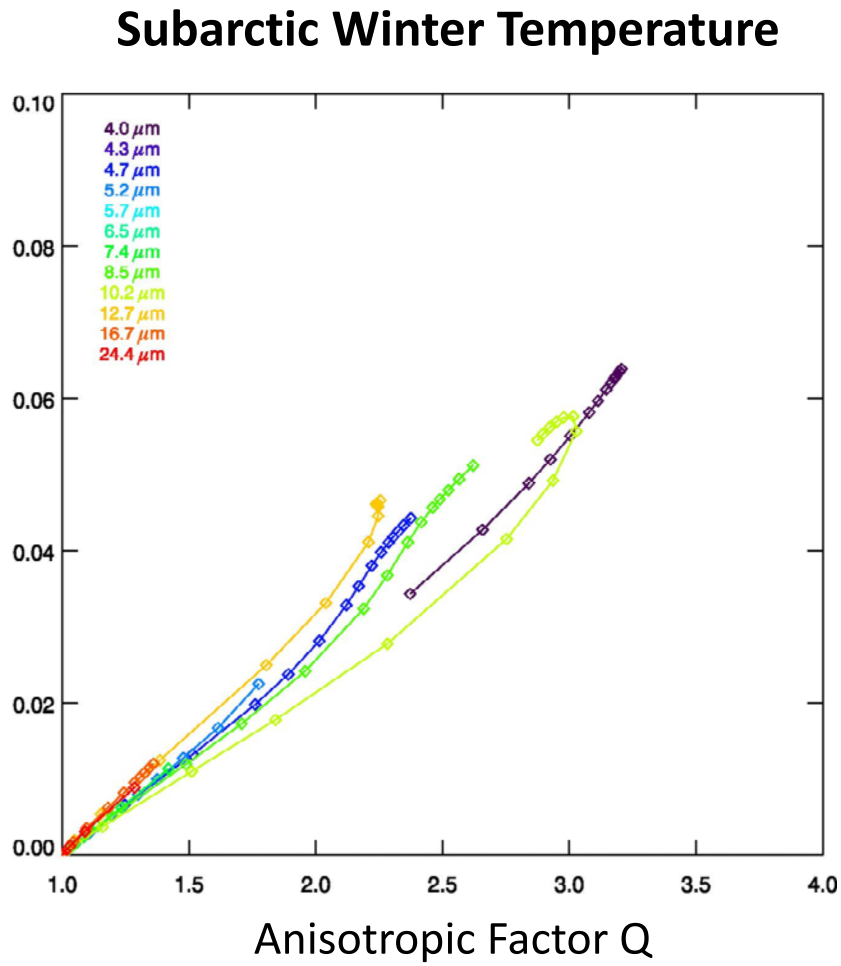


Window channel has larger anisotropy factor.

Drier atmosphere has larger anisotropy factor.

"Anisotropic Factor Q" vs "Albedo Correction Factor Δα"



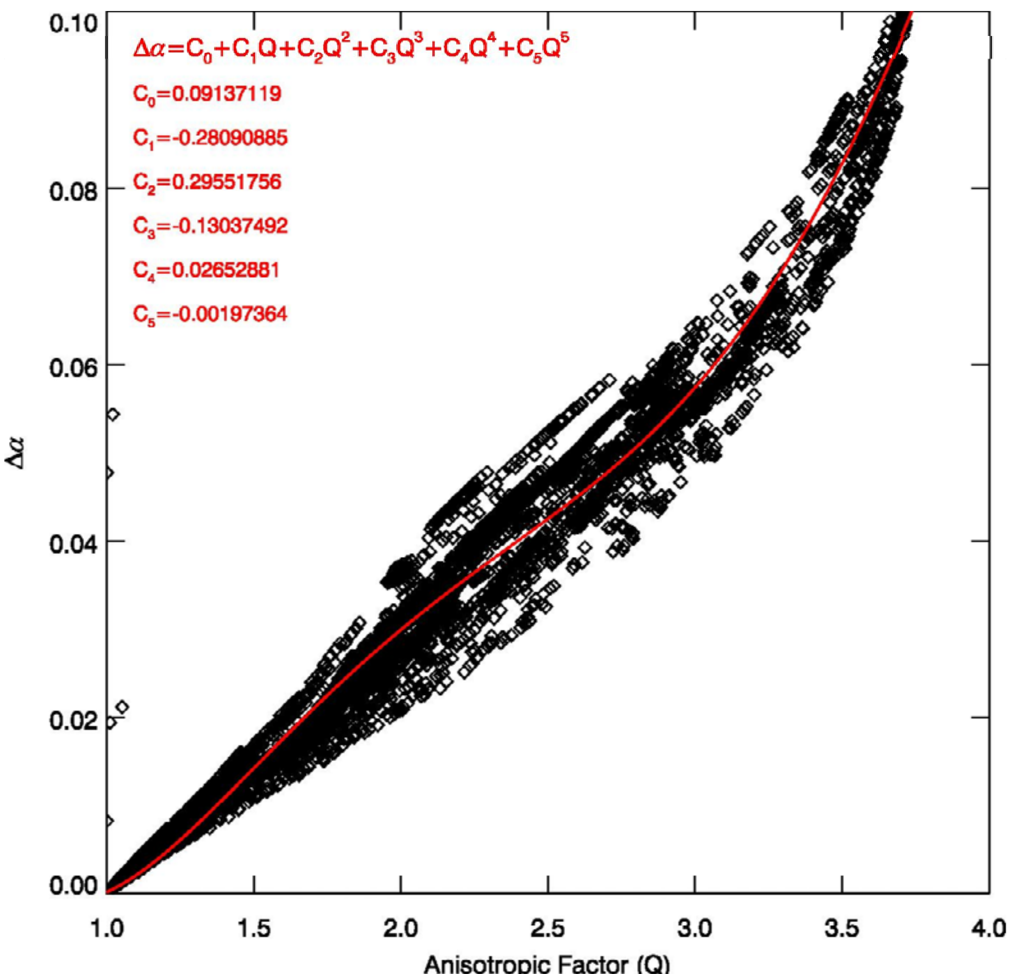


As the anisotropy factor increases, albedo correction factor increases.
The relation is hardly affected by wavelength and temperature profiles.

Preliminary Results for SYN Ed4

SAW	Emissivity	Albedo	Sfc LW Up	Sfc Lw Dn
Ed4	0.9722	0.0278	245.562	182.846
X.Huang	0.9184	0.0816	243.557	182.838
X.Huang_Cor	0.9184	0.0935	244.757	182.841
X.Huang minus Ed4	-0.0538	0.0538	-2.005	-0.008
X.Huang_Cor minus Ed4	-0.0538	0.0657	-0.805	-0.005
SAS				
Ed4	0.9722	0.0278	381.883	306.876
X.Huang	0.9184	0.0816	380.142	306.869
X.Huang_Cor	0.9184	0.0926	382.472	306.876
X.Huang -Ed4	-0.0538	0.0538	-1.741	-0.007
X.Huang_Cor -Ed4	-0.0538	0.0648	0.589	0
MLW				
Ed4	0.9722	0.0278	307.645	231.549
X.Huang	0.9184	0.0816	305.566	231.54
X.Huang_Cor	0.9184	0.0902	306.484	231.544
X,Huang -Ed4	-0.0538	0.0538	-2.079	-0.009
X,Huang_Cor -Ed4	-0.0538	0.0624	-1.161	-0.005
MLS				
Ed4	0.9722	0.0278	421.08	356.459
X.Huang	0.9184	0.0816	419.742	356.455
X.Huang_Cor	0.9184	0.0886	421.508	356.46
X.Huang -Ed4	-0.0538	0.0538	-1.338	-0.004
X.Huang_Cor -Ed4	-0.0538	0.0608	0.428	0.001
TROP				
Ed4	0.9722	0.0278	456.994	402.111
X.Huang	0.9184	0.0816	455.885	402.108
X.Huang_Cor	0.9184	0.0869	457.515	402.112
X.Huang -Ed4	-0.0538	0.0538	-1.109	-0.003
X.Huang_Cor -Ed4	-0.0538	0.0591	0.521	0.001

Albedo Conversion Factor for Various Temperature and Humidity Profiles



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

$$
\begin{aligned}
\Delta\alpha = \; & 0.09137119 \\
& -0.28090885Q \\
& +0.29551756\,Q^2 \\
& -0.13037492\,Q^3 \\
& +0.02652881\,Q^4 \\
& -0.00197364\,Q^5
\end{aligned}
$$

$Q = I^{-}(\mu=0.21) / I^{-}(\mu=0.98)$

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

Summary and Conclusions

- SYNI Org used spectral ocean emissivity, which is larger than those shown in other studies (Feldman et al., 2014; Xianglei).
- Implementing imaginary parts of refractive decreases ocean emissivity, also reducing surface upward irradiance.
- Ocean emissivity decreases (albedo increases) as zenith angle of the incoming radiance increase.
- Since dowelling radiance is anisotropic, use of spherically averaged ocean emissivity causes low biases in surface upward irradiance. The biases are larger in window band.
- To remove the low biases, we implement correction factor for spherical albedo. The correction factor decreases with humidity. Also correction factor increase with atmosphere temperature.
- Compared to humidity, anisotropic factor defined from two stream output explains albedo correction better.
- Since imaginary refractive index decreases SFCUP irradiance, while albedo correction factor increases SFCUP irradiances, total changes in SYN products are order of 1-2 W m^{-2} due to cancellation.