Angular Distribution Models For CERES-TRMM

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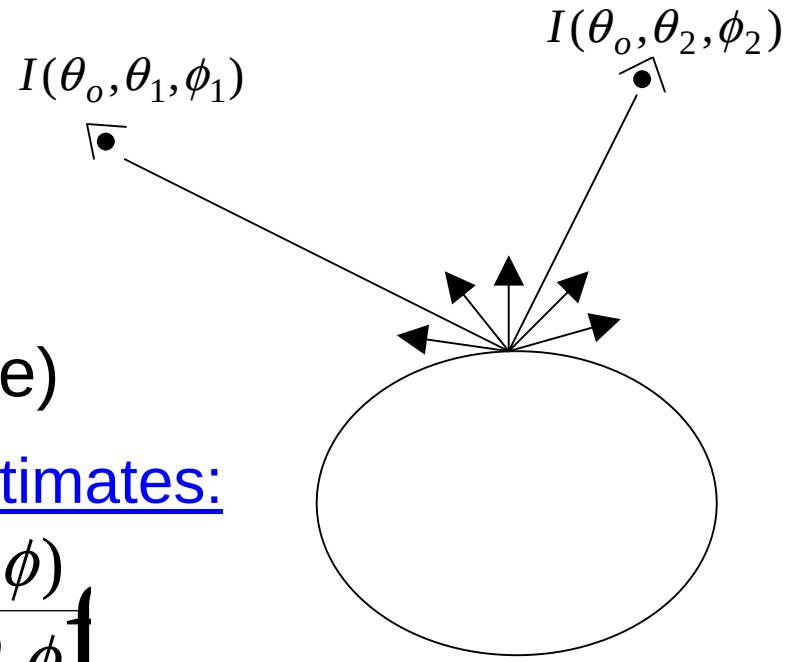
Outline

1. Preliminary SW ADMs for CERES-TRMM Edition 2

2. Preliminary LW and WN ADMs for CERES-TRMM Edition 2

3. Early Validation of CERES-TRMM SSF Edition 1

SW Flux & Albedo Estimation from ADMs



Reflectance (isotropic albedo):

$$r\left(\theta_o,\theta,\phi\right) = \frac{\pi I(\theta_o,\theta,\phi)}{\cos\theta_o \; S_o}$$

$(I(\theta_o,\theta,\phi) =$ measured radiance)

Instantaneous Flux & Albedo Estimates:

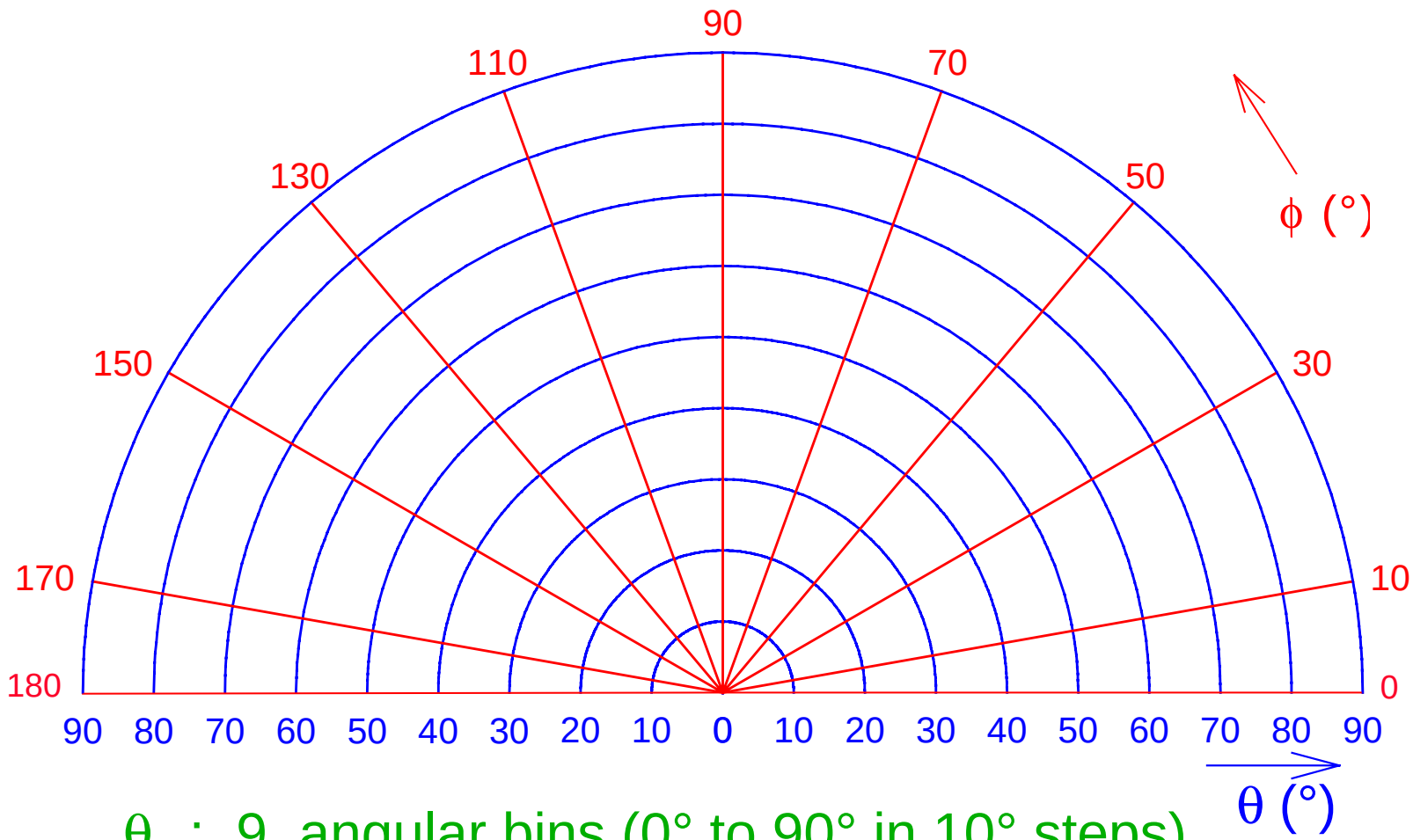
$$\hat{F} = \frac{\pi I(\theta_o,\theta,\phi)}{R_j(\theta_o,\theta,\phi)} \qquad \hat{A} = \frac{r(\theta_o,\theta,\phi)}{R_j\left(\theta_o,\theta,\phi\right)}$$

where,

$R_j(\theta_o,\theta,\phi)$ = SW Anisotropic Factor

$$R_j(\theta_o,\theta,\phi) = \frac{\bar{r}_j(\theta_o,\theta,\phi)}{\bar{A}_j\left(\theta_o\right)} = \frac{\bar{r}_j(\theta_o,\theta,\phi)}{\pi^{-1}\int_0^{2\pi}\int_0^{\pi} \bar{r}_j(\theta_o,\theta,\phi)\cos\theta d\theta d\phi}$$

CERES SW ADM Angular Bin Definitions



θ_o : 9 angular bins (0° to 90° in 10° steps)

θ : 9 angular bins (0° to 90° in 10° steps)

ϕ : 10 angular bins (0° to 180° in 10° or 20° steps)

Anisotropic Model Scene Type Stratification

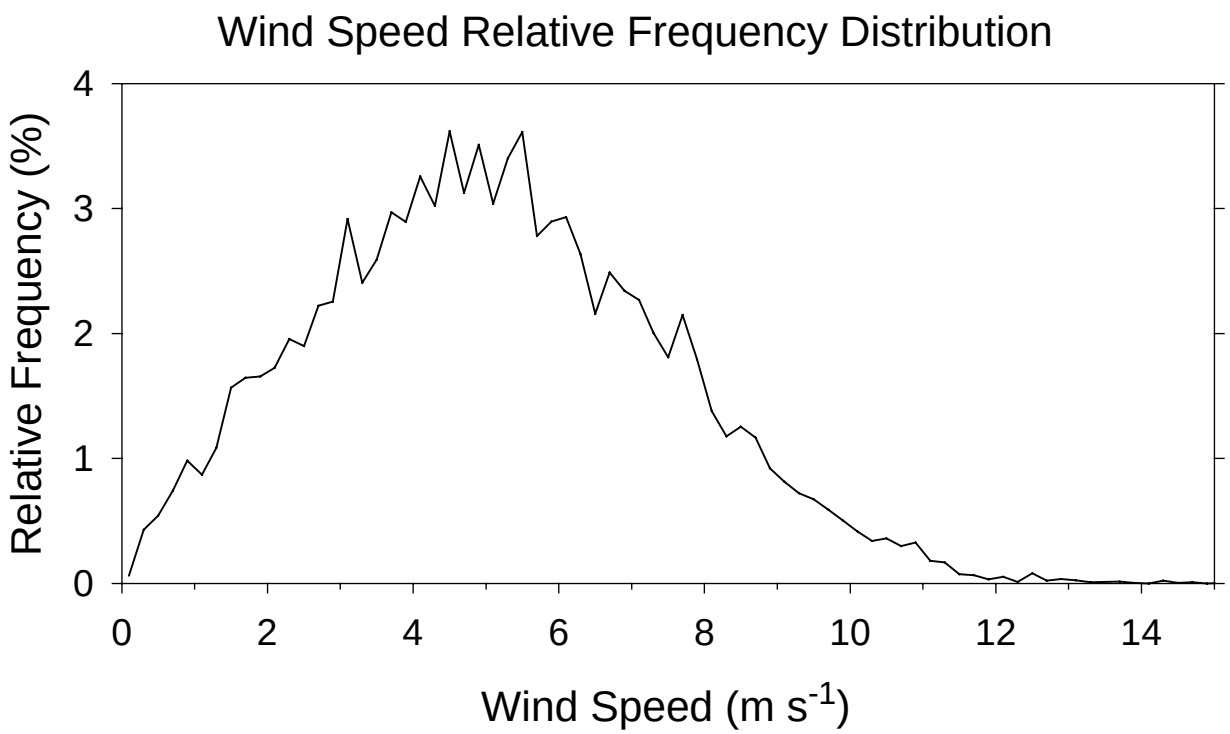
Spacecraft/Mission	Cloud	Surface Type	Total
TIROS 2, 3, 4	N/A	N/A	isotropy
TIROS 7 (Arking and Levine, 1967)	Global	Global	1
Nimbus 2, 3 (Rashke et al. 1973)	Cloud/Land	Ocean Snow	3
Nimbus-6, 7 (Taylor and Stowe, 1984; Jacobowitz et al., 1984)	All Cloud	Ocean Land Snow/Ice	4
ERBE (Smith et al., 1986; Suttles et al., 1988)	Clear Partly cloudy Mostly cloudy Overcast	Ocean Land Desert Snow Land-Ocean Mix	12

Preliminary Scene Types for CERES-TRMM SW ADMs

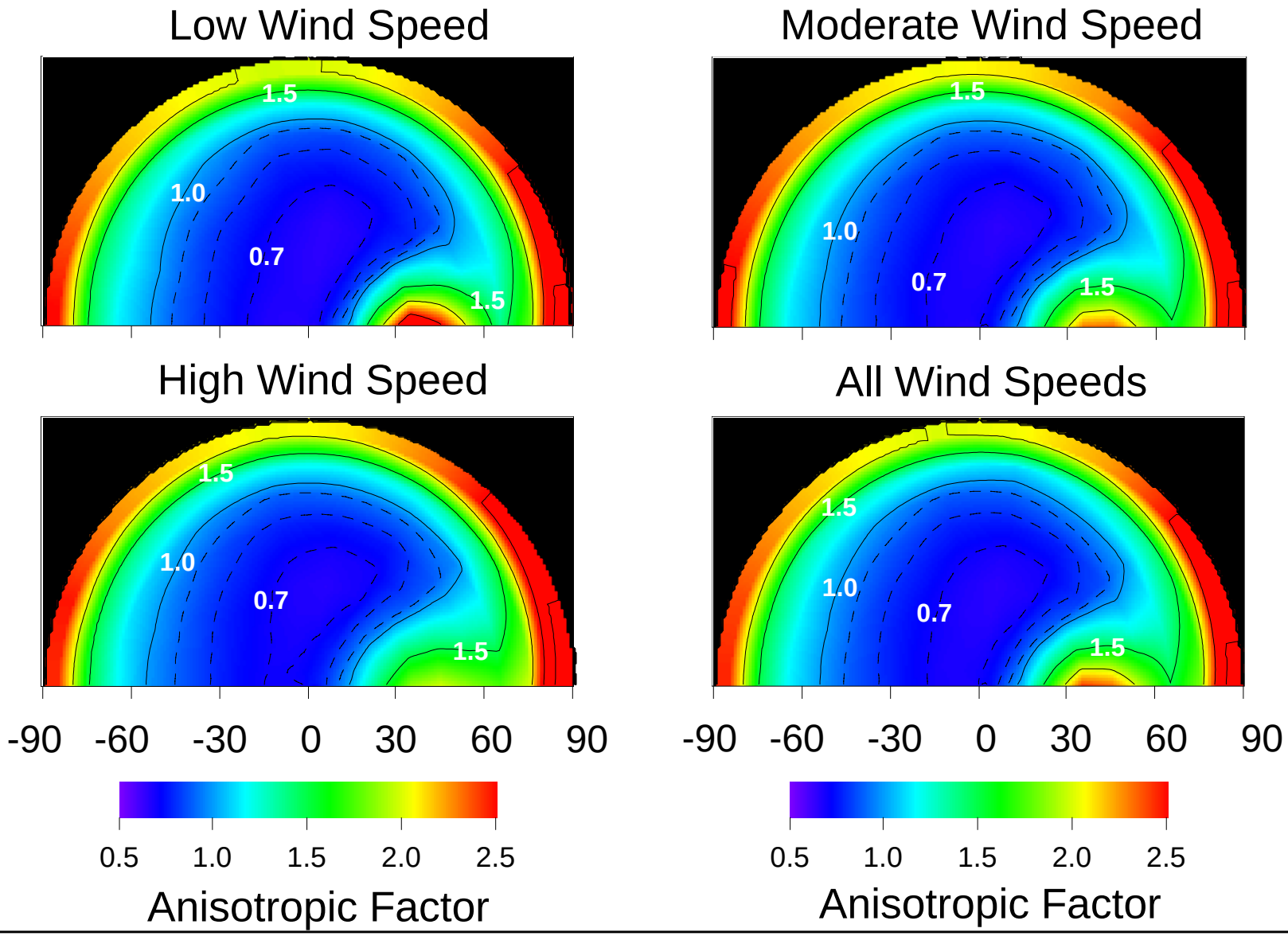
ADM Category		Scene Type Stratification	Actual Total
Clear	Ocean	- 3 Wind Speed Intervals	3
	Land	- 2 IGBP Type Groupings	2
	Desert	- Bright and Dark	2
	Snow	- Theoretical	1
Cloud	Ocean	- Liquid and Ice - 12 Cloud Fraction Intervals - 14 Optical Depth Intervals	62 (L) 53 (I)
	Land	- 2 IGBP Type Groupings - Liquid and Ice - 5 Cloud Fraction Intervals - 6 Optical Depth Intervals	45
	Desert	- Bright and Dark Deserts - Liquid and Ice - 5 Cloud Fraction Intervals - 6 Optical Depth Intervals	33
	Snow	- Theoretical	1
Total			202

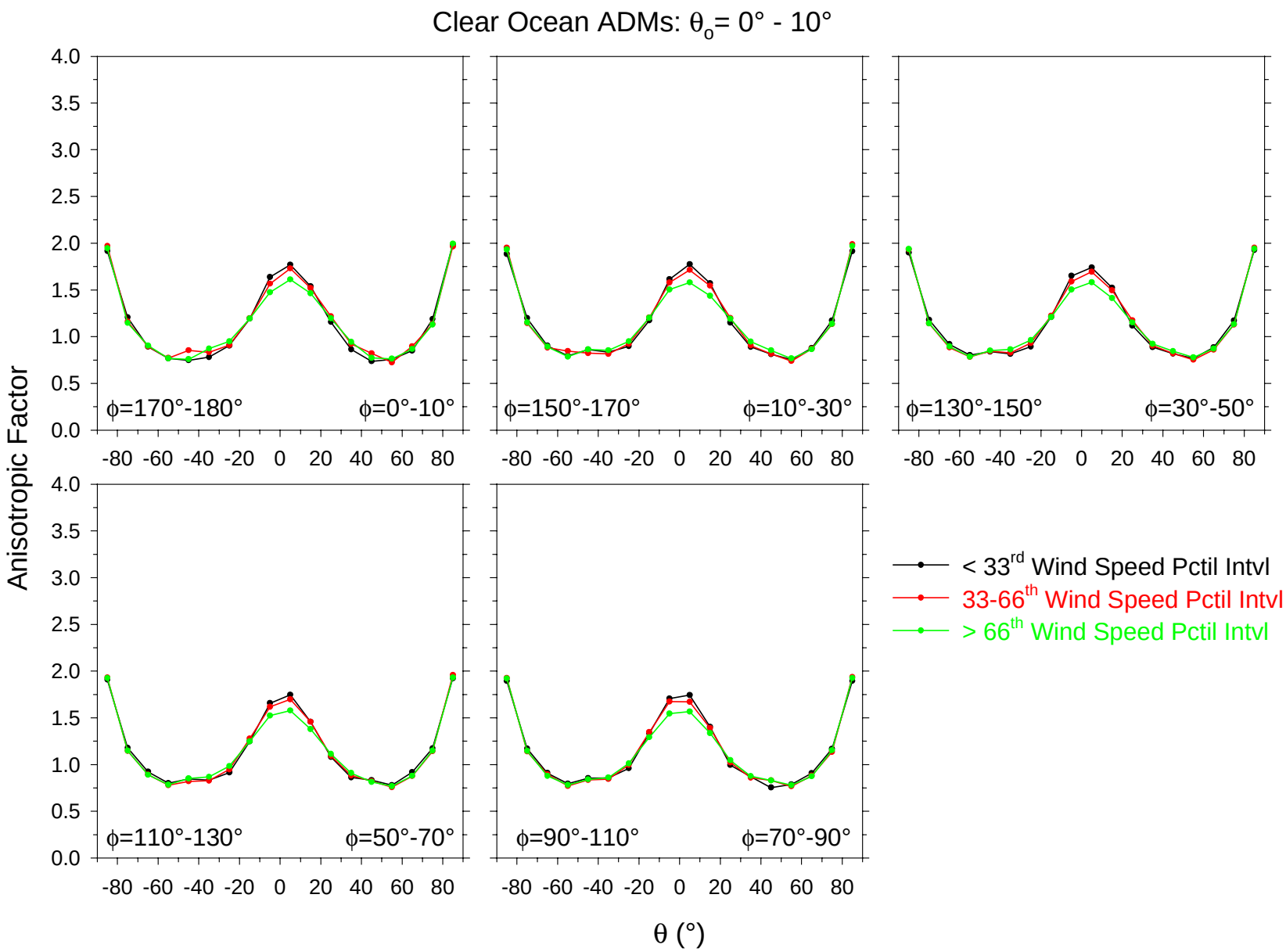
Clear Ocean ADM Scene Types

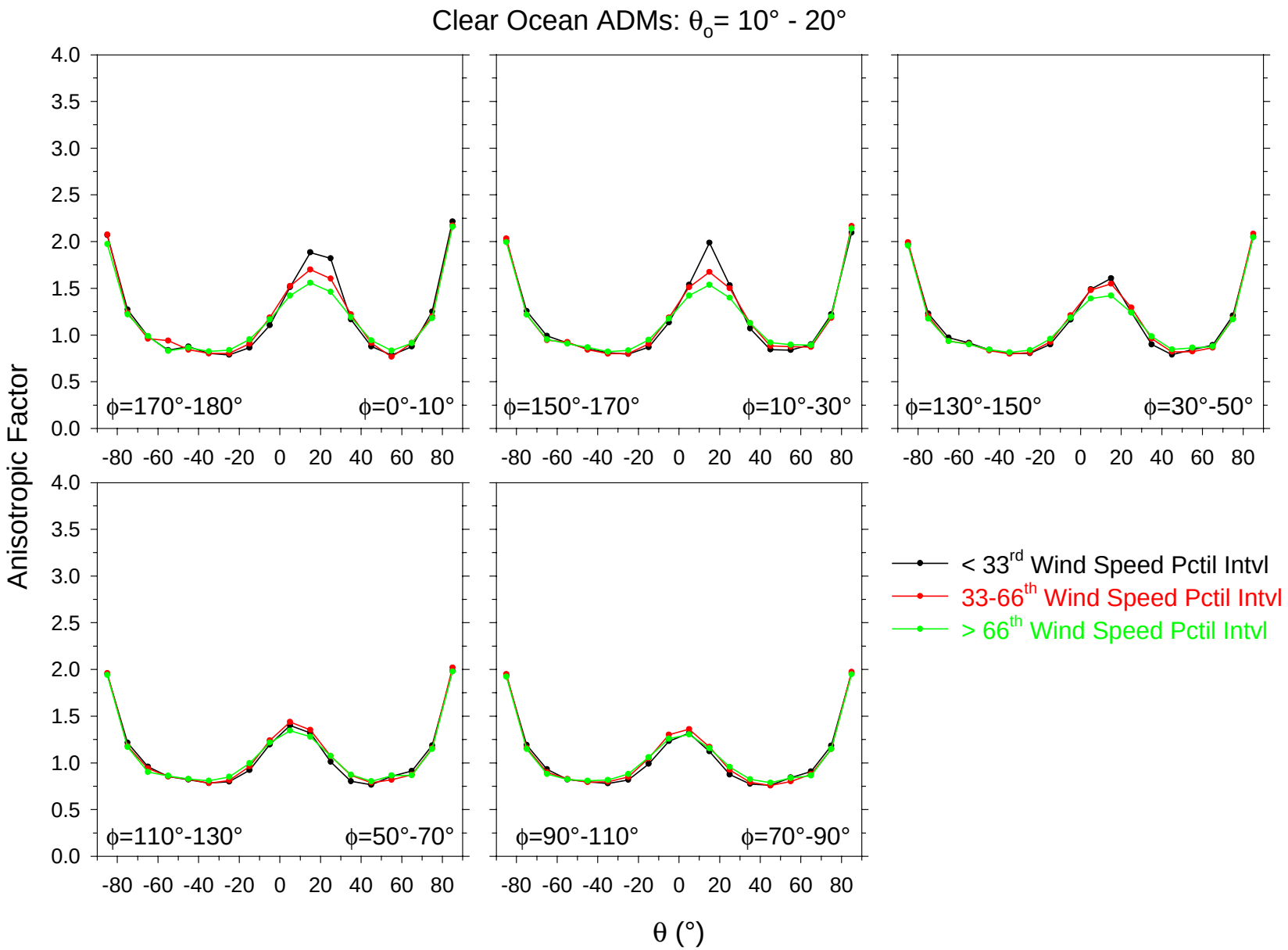
Wind Speed Pctil	Wind Speed (m s^{-1})
< 33th	< 4
33 - 66	4 - 6
> 66	> 6

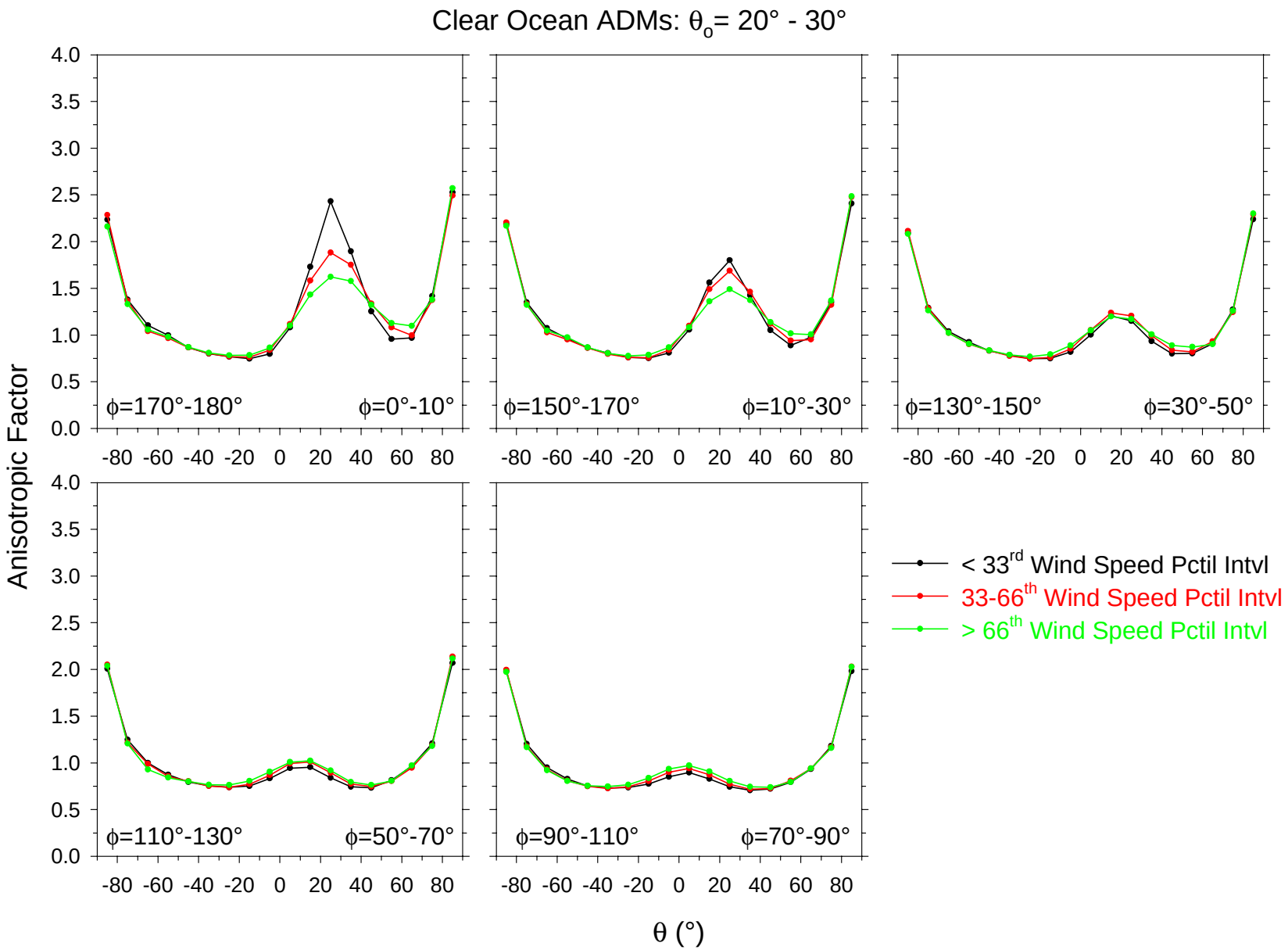


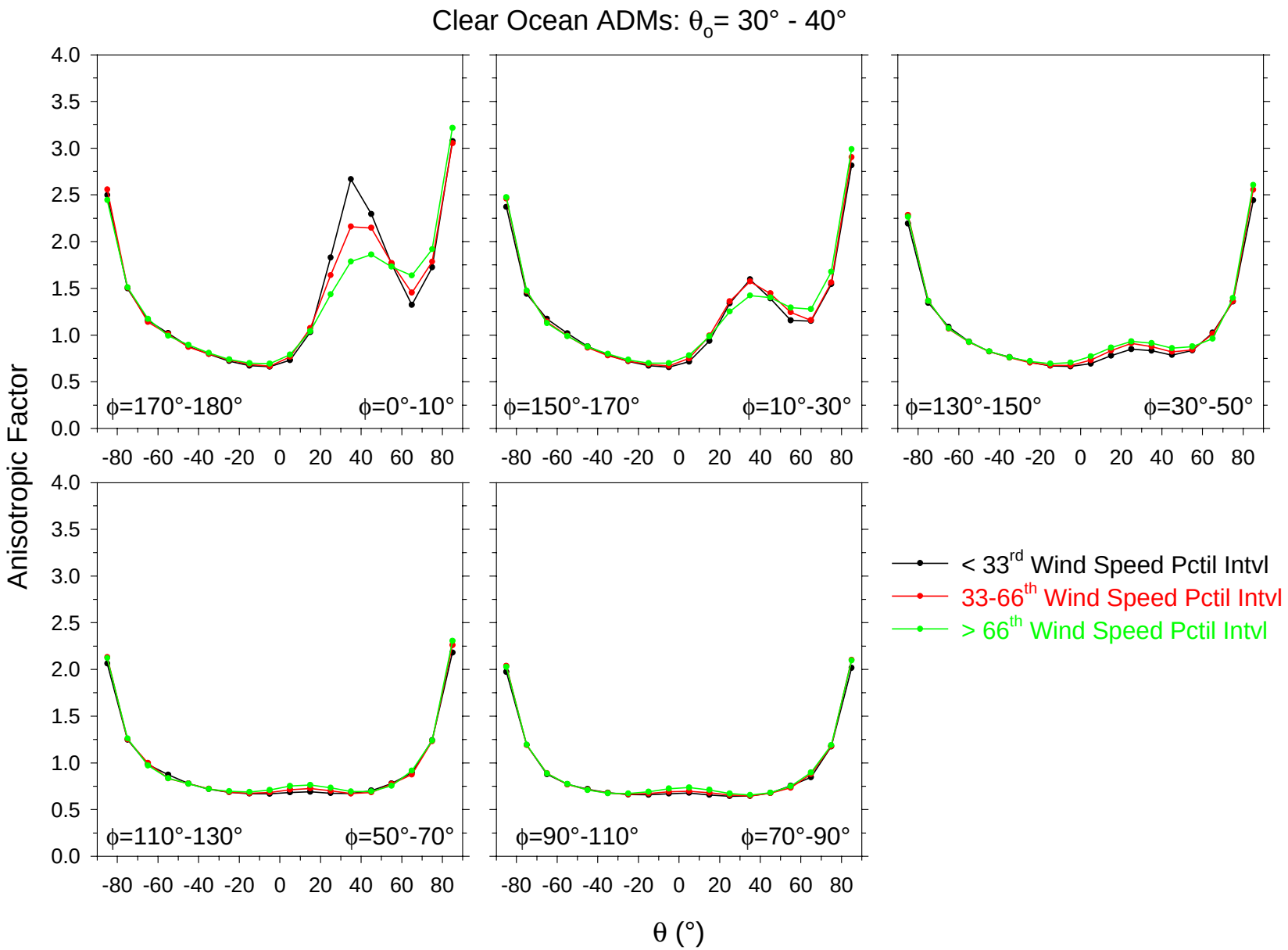
Clear Ocean ADMs: θ_o=30°-40°

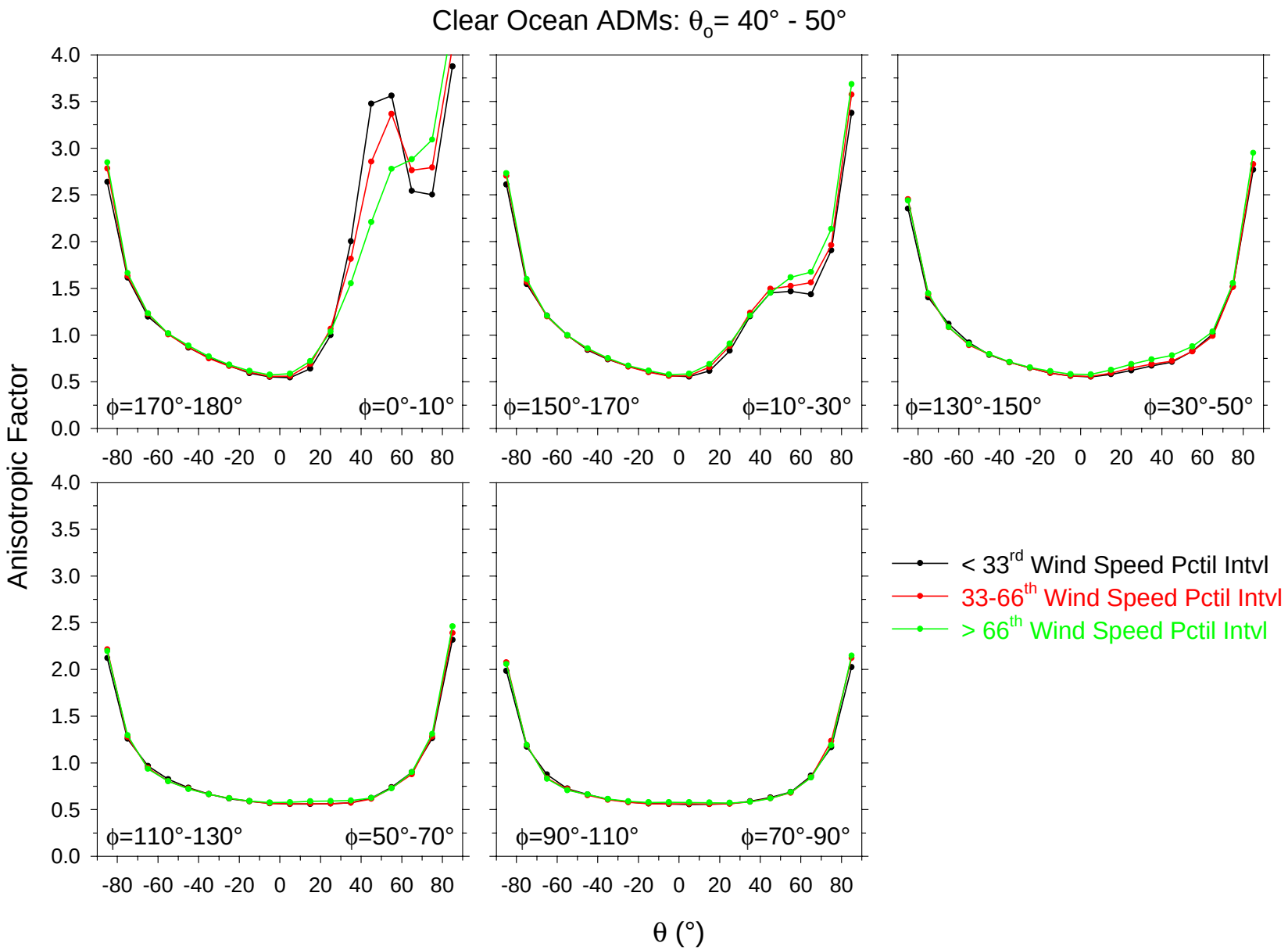


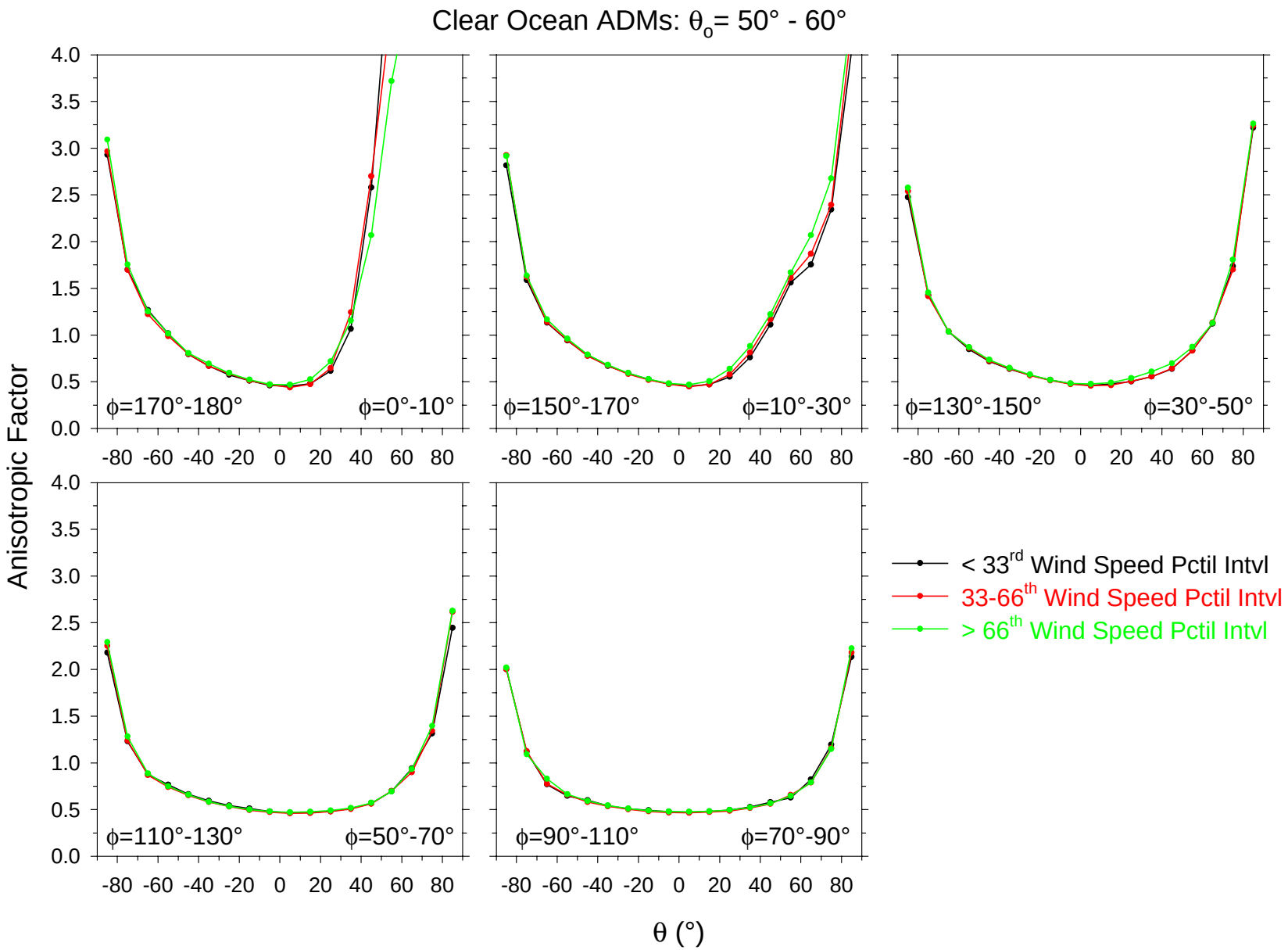

Clear Ocean ADMs: θo= 0° - 10°
Anisotropic Factor
θ (°)
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
< 33rd Wind Speed Pctil Intvl
33-66th Wind Speed Pctil Intvl
> 66th Wind Speed Pctil Intvl

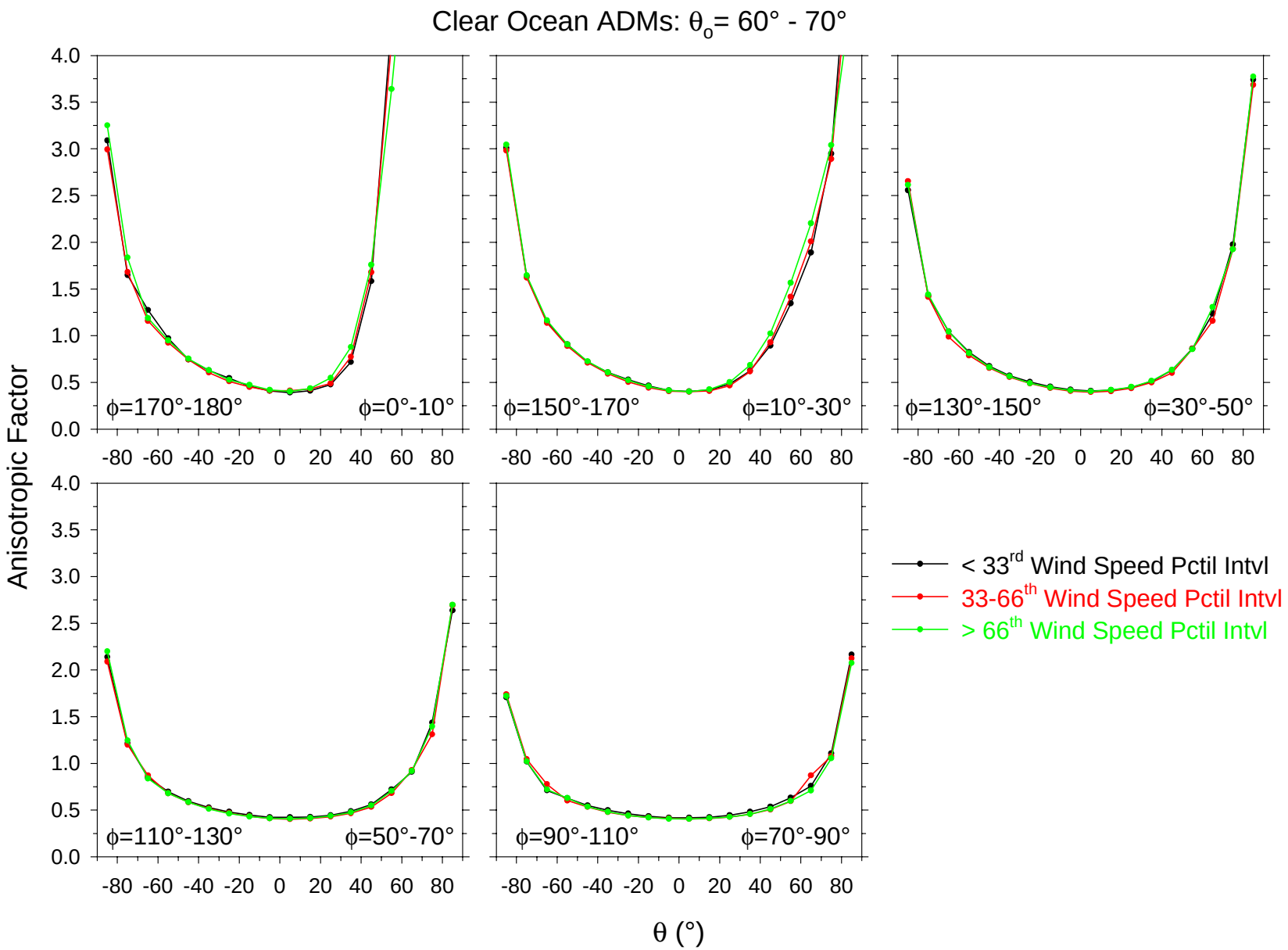

Clear Ocean ADMs: θo= 10° - 20°
Anisotropic Factor
θ (°)
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
< 33rd Wind Speed Pctil Intvl
33-66th Wind Speed Pctil Intvl
> 66th Wind Speed Pctil Intvl

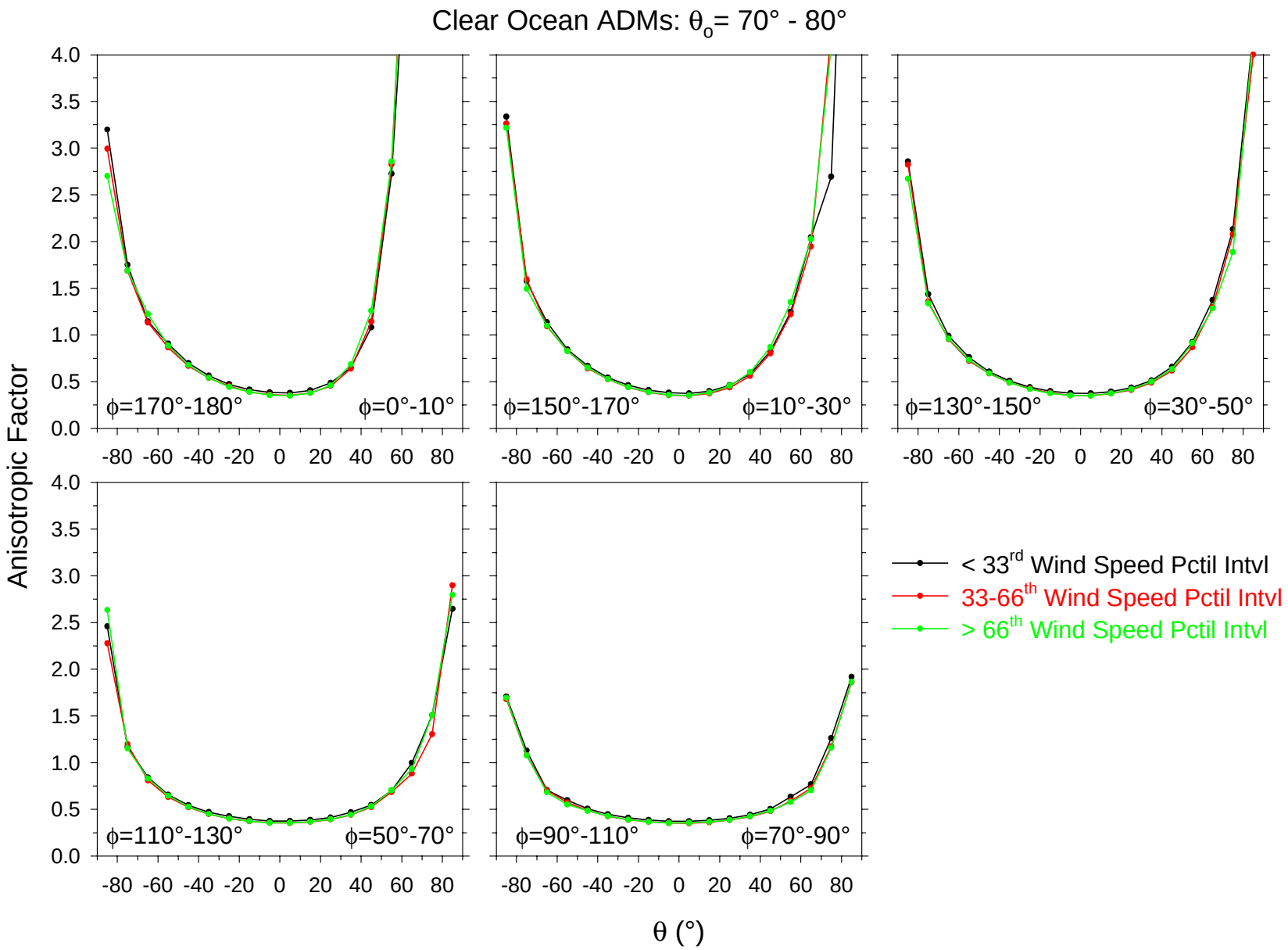

Clear Ocean ADMs: θo= 20° - 30°
Anisotropic Factor
θ (°)
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
< 33rd Wind Speed Pctil Intvl
33-66th Wind Speed Pctil Intvl
> 66th Wind Speed Pctil Intvl

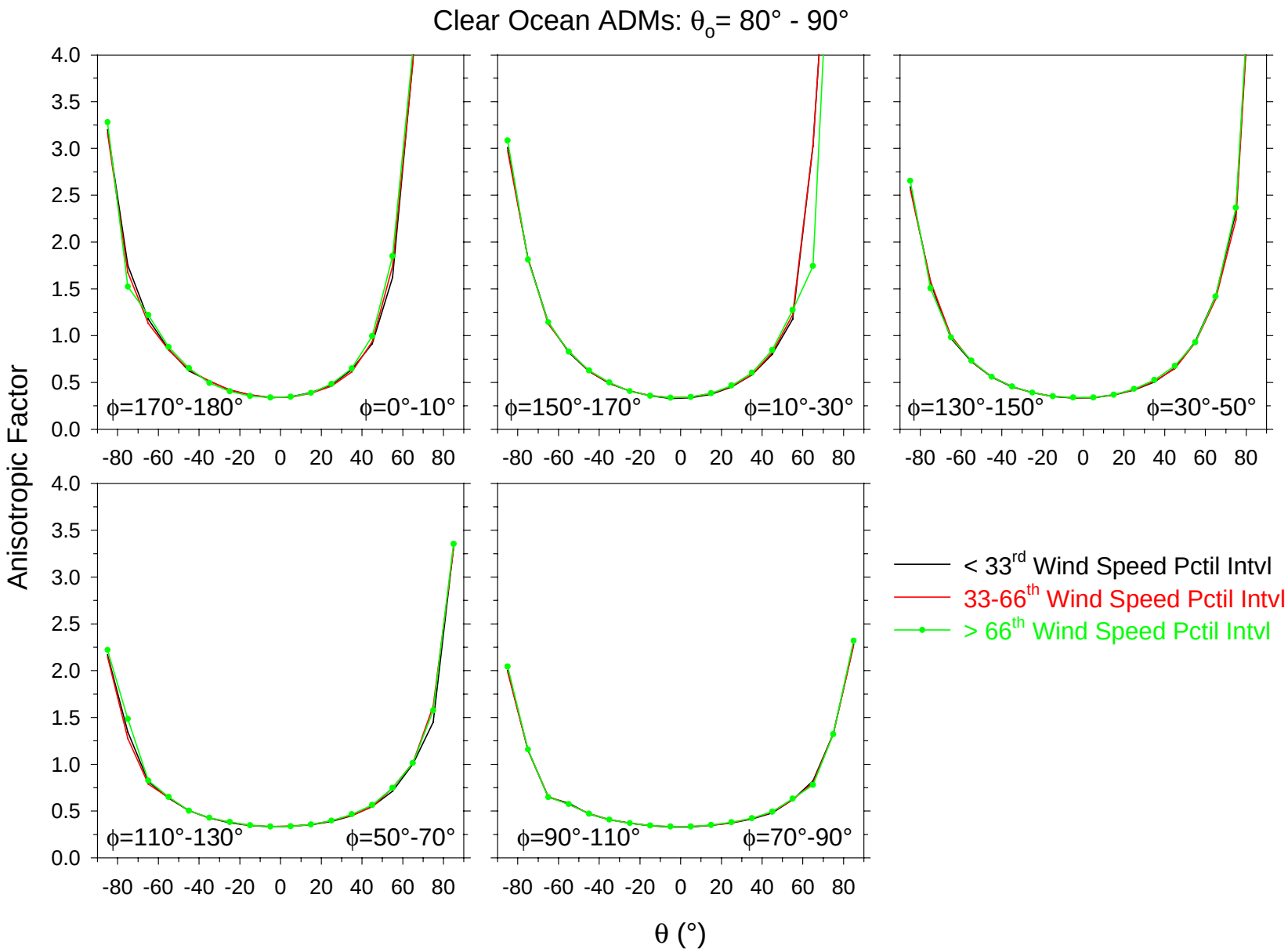

Clear Ocean ADMs: θo= 30° - 40°
Anisotropic Factor
θ (°)
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
< 33rd Wind Speed Pctil Intvl
33-66th Wind Speed Pctil Intvl
> 66th Wind Speed Pctil Intvl

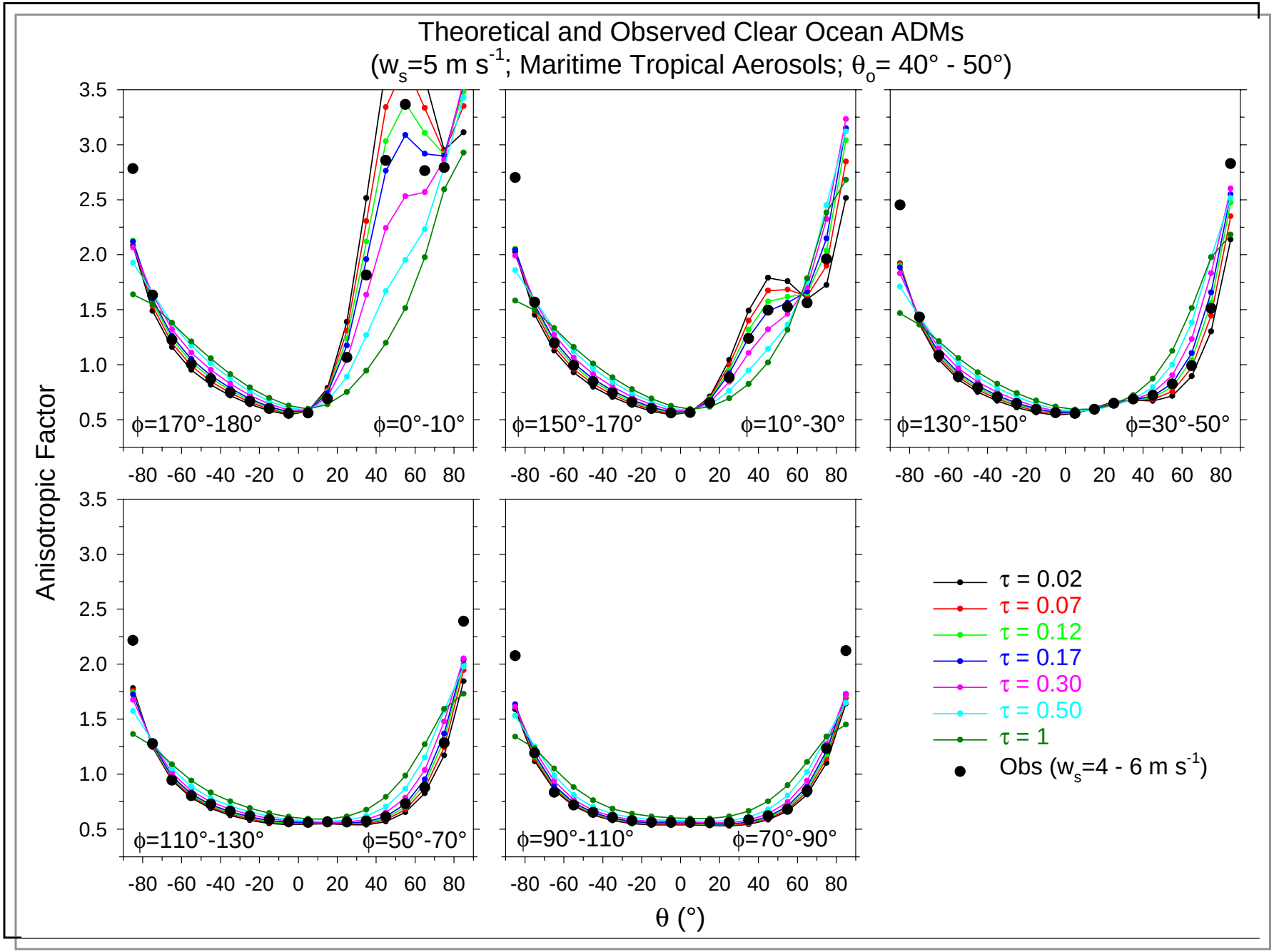

Clear Ocean ADMs: θo= 40° - 50°
Anisotropic Factor
θ (°)
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
< 33rd Wind Speed Pctil Intvl
33-66th Wind Speed Pctil Intvl
> 66th Wind Speed Pctil Intvl


Clear Ocean ADMs: θo= 50° - 60°
Anisotropic Factor
θ (°)
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
< 33rd Wind Speed Pctil Intvl
33-66th Wind Speed Pctil Intvl
> 66th Wind Speed Pctil Intvl

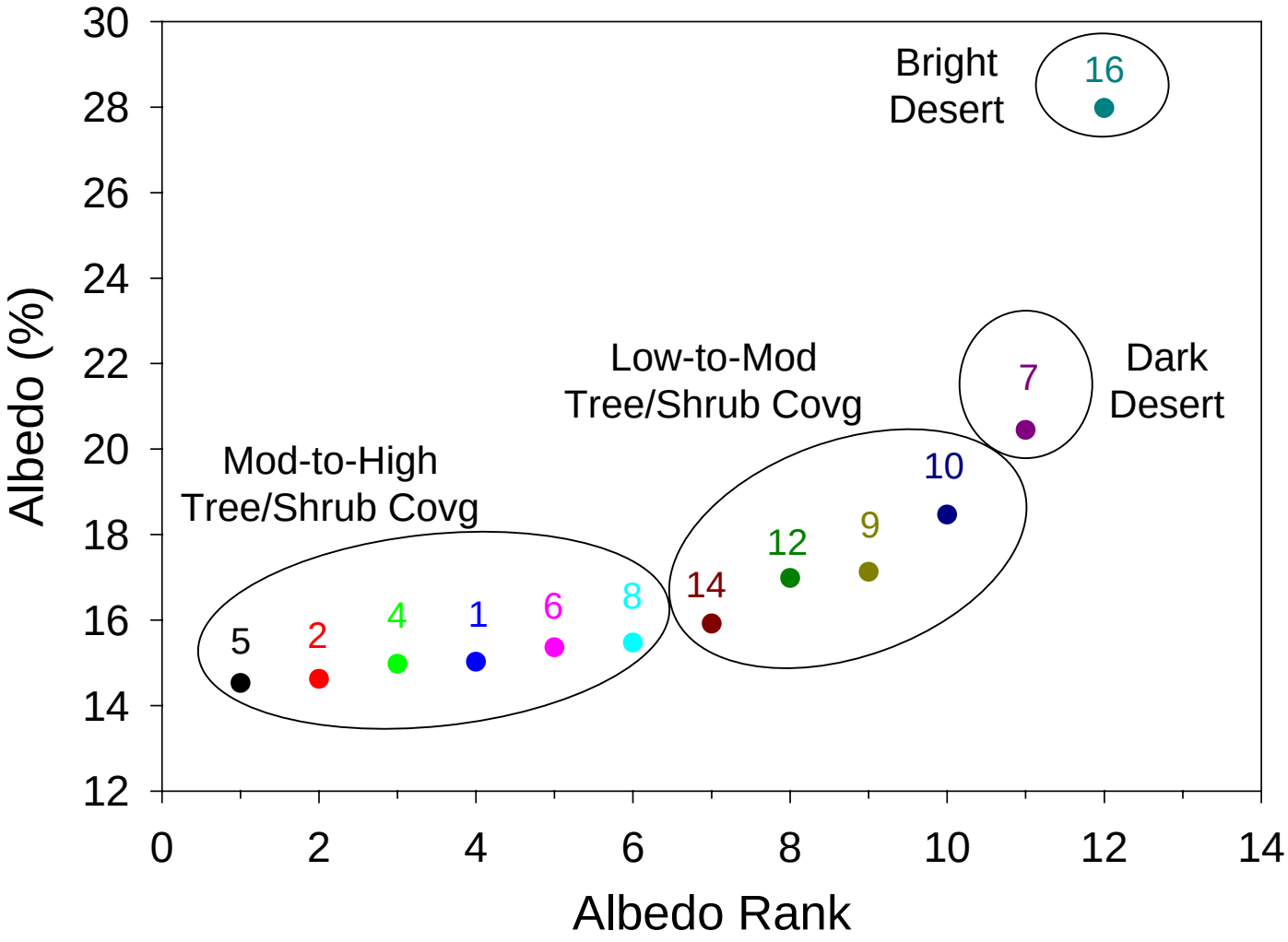

Clear Ocean ADMs: θo= 60° - 70°
Anisotropic Factor
θ (°)
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
< 33rd Wind Speed Pctil Intvl
33-66th Wind Speed Pctil Intvl
> 66th Wind Speed Pctil Intvl


Clear Ocean ADMs: θo= 70° - 80°
Anisotropic Factor
θ (°)
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
< 33rd Wind Speed Pctil Intvl
33-66th Wind Speed Pctil Intvl
> 66th Wind Speed Pctil Intvl


Clear Ocean ADMs: θo= 80° - 90°
Anisotropic Factor
θ (°)
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
< 33rd Wind Speed Pctil Intvl
33-66th Wind Speed Pctil Intvl
> 66th Wind Speed Pctil Intvl

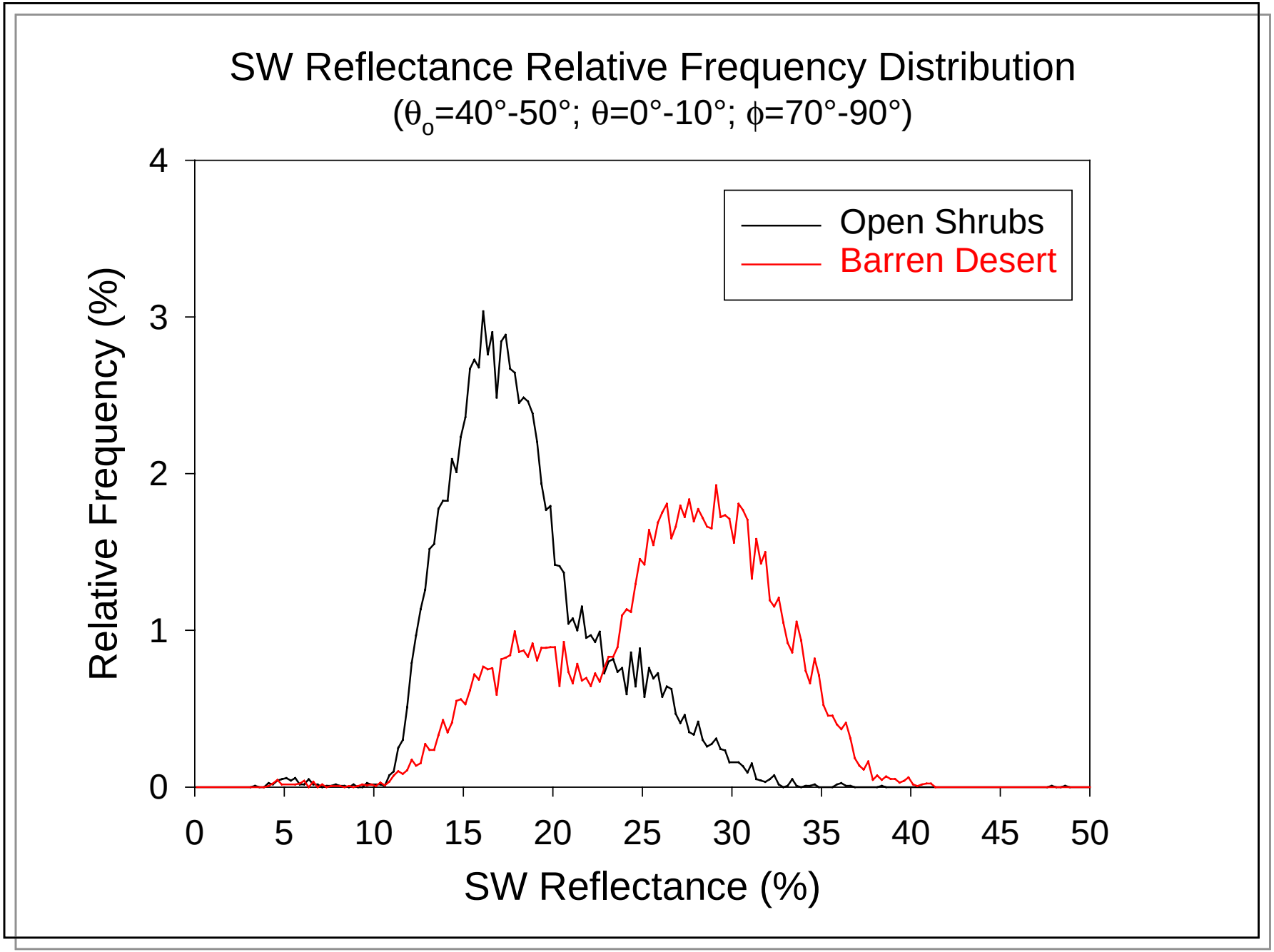

Theoretical and Observed Clear Ocean ADMs
(w_s=5 m s^-1; Maritime Tropical Aerosols; θ_o= 40° - 50°)
Anisotropic Factor
θ (°)
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
τ = 0.02
τ = 0.07
τ = 0.12
τ = 0.17
τ = 0.30
τ = 0.50
τ = 1
Obs (w_s=4 - 6 m s^-1)

Land and Desert IGBP Type Groupings

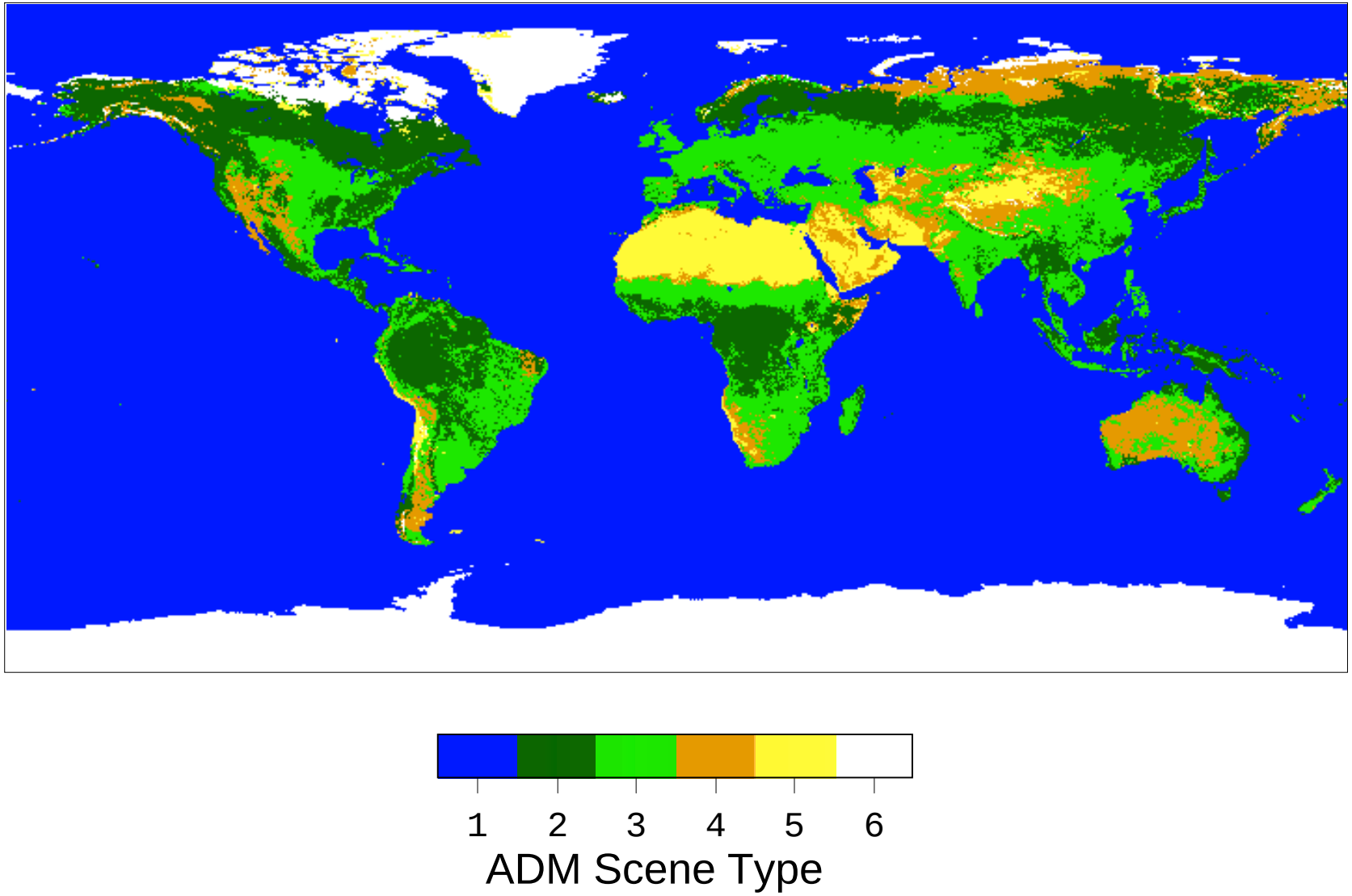


Clear Land and Desert ADMs

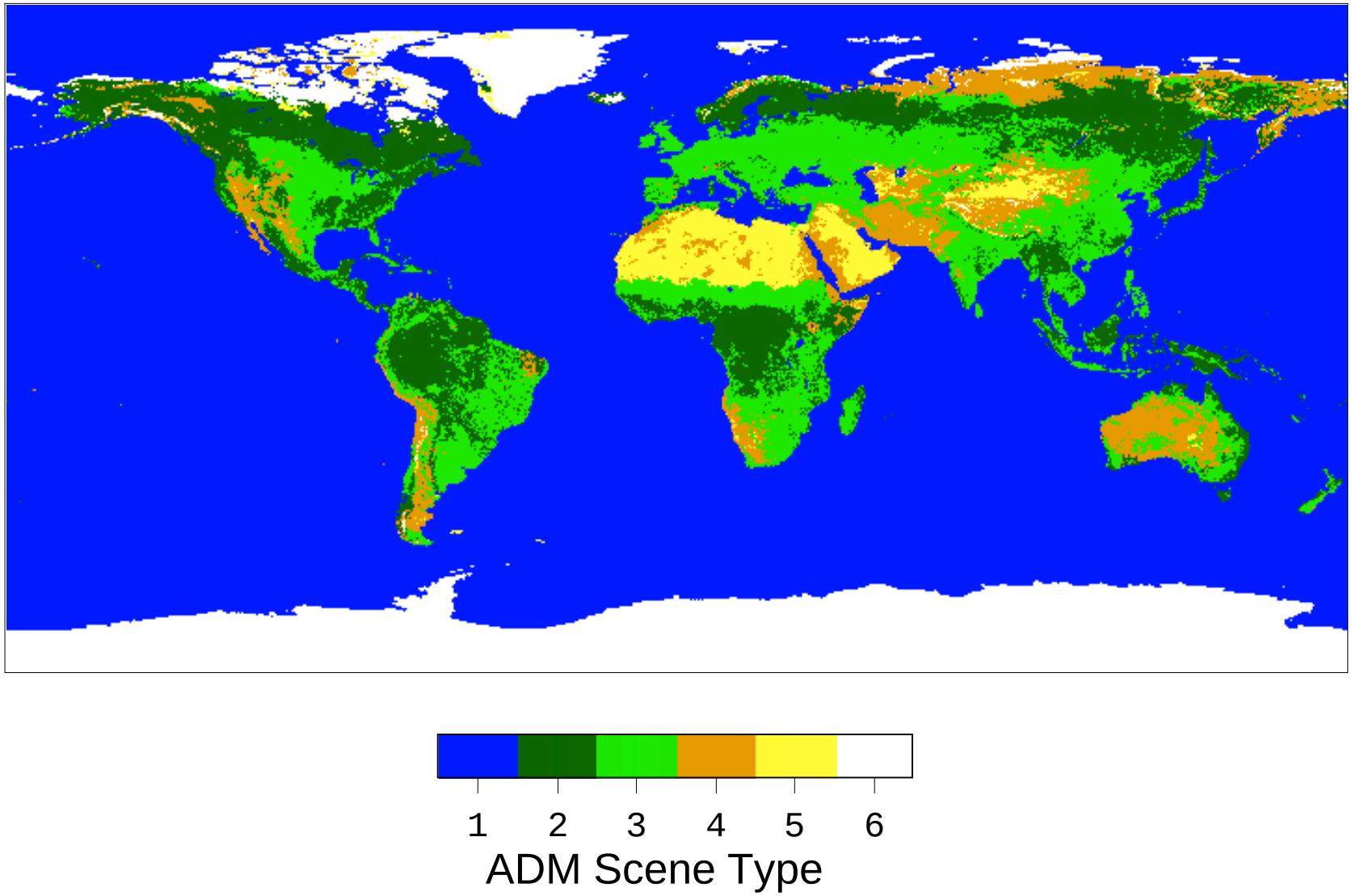
ADM Surface Type	IGBP Type
Moderate-to-High Tree/Shrub Coverage (Mostly Trees with > 60% Coverage)	- Forests (1-5) - Closed Shrubs (6) -Woody Savannas (8)
Low-to-Moderate Tree/Shrub Coverage (Mostly Shrubs with < 60% Coverage)	- Savannas (9) - Grassland (10) - Wetlands (11) - Crops (12) - Urban (13) - Crop/Mosaic (14)
Dark Desert	- Open Shrubs (modified 7)
Bright Desert	- Barren Desert (modified 16)


SW Reflectance Relative Frequency Distribution
(θ_o=40°-50°; θ=0°-10°; ϕ=70°-90°)
Open Shrubs
Barren Desert
Relative Frequency (%)
SW Reflectance (%)
0
1
2
3
4
0
5
10
15
20
25
30
35
40
45
50

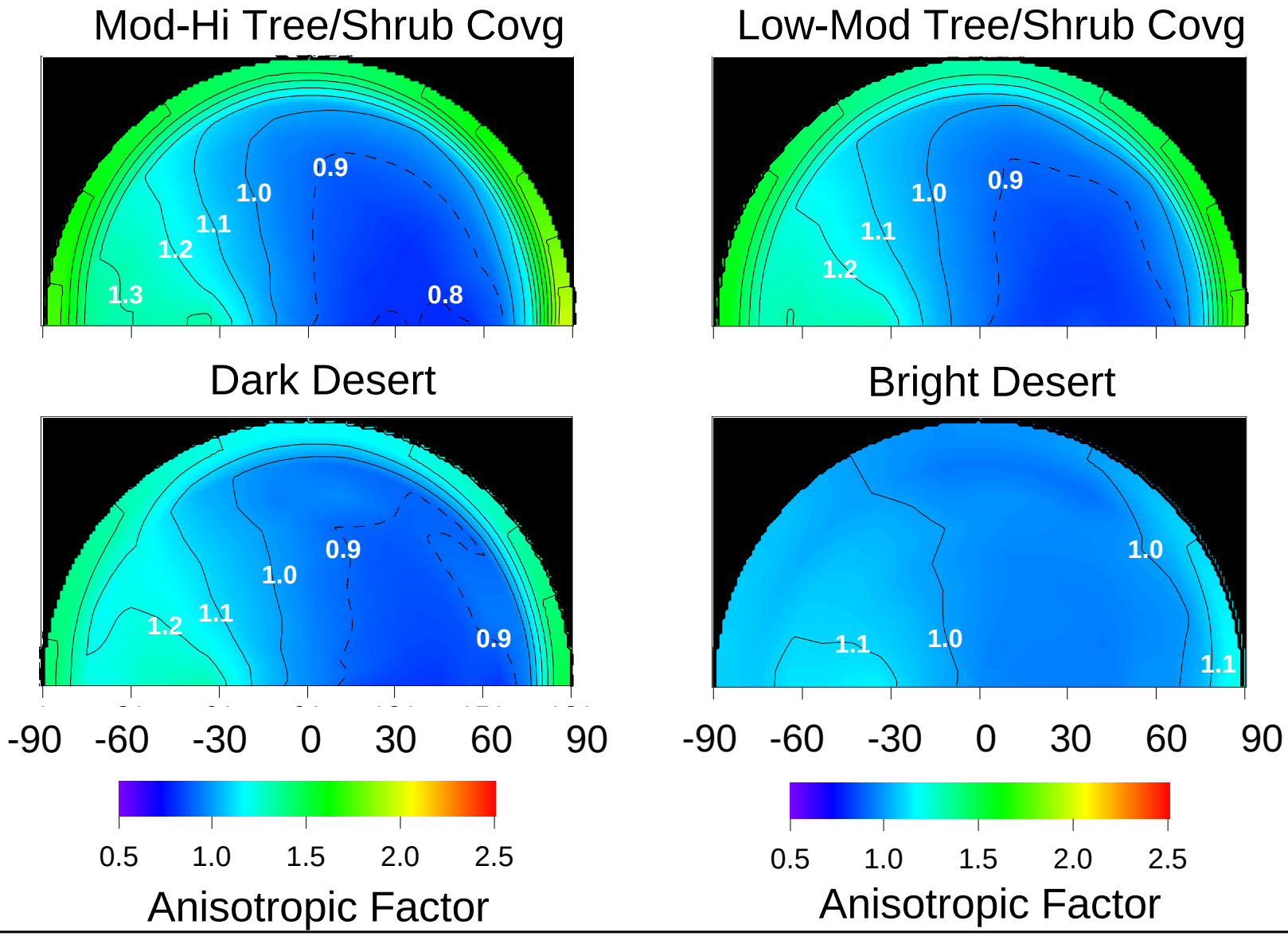
ADM Scene Type Groupings With IGBP Deserts

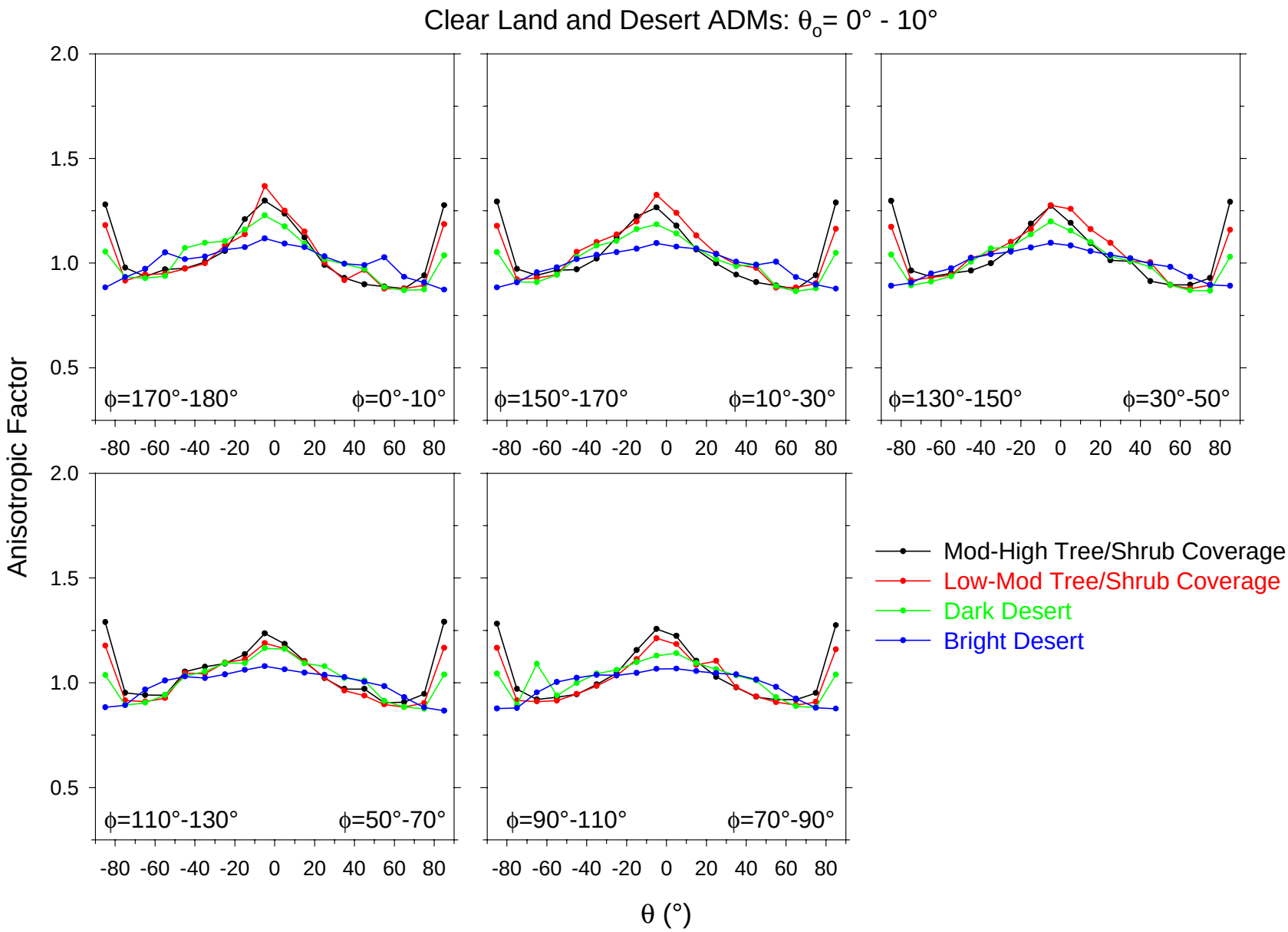


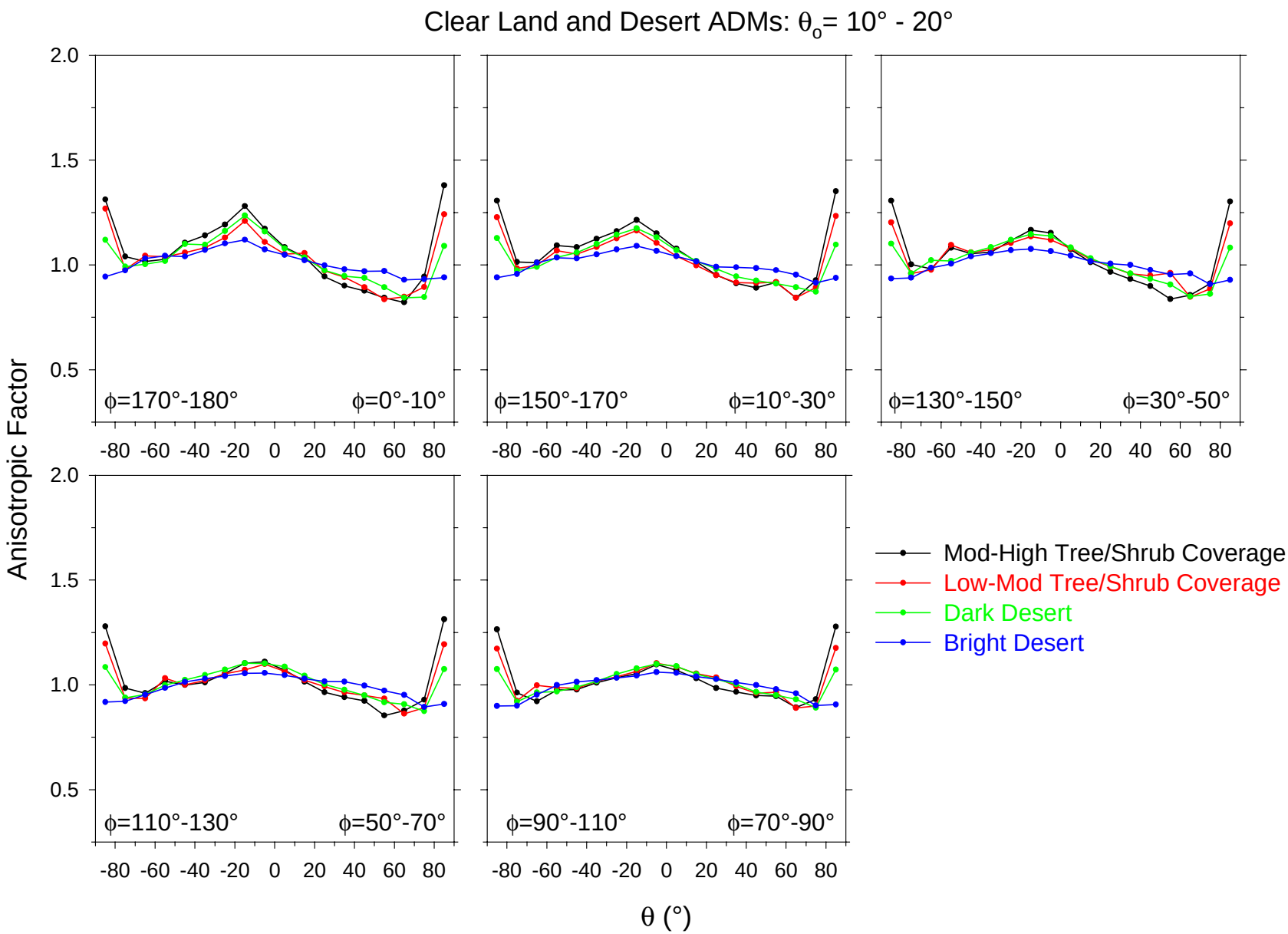
ADM Scene Type Groupings With New Deserts

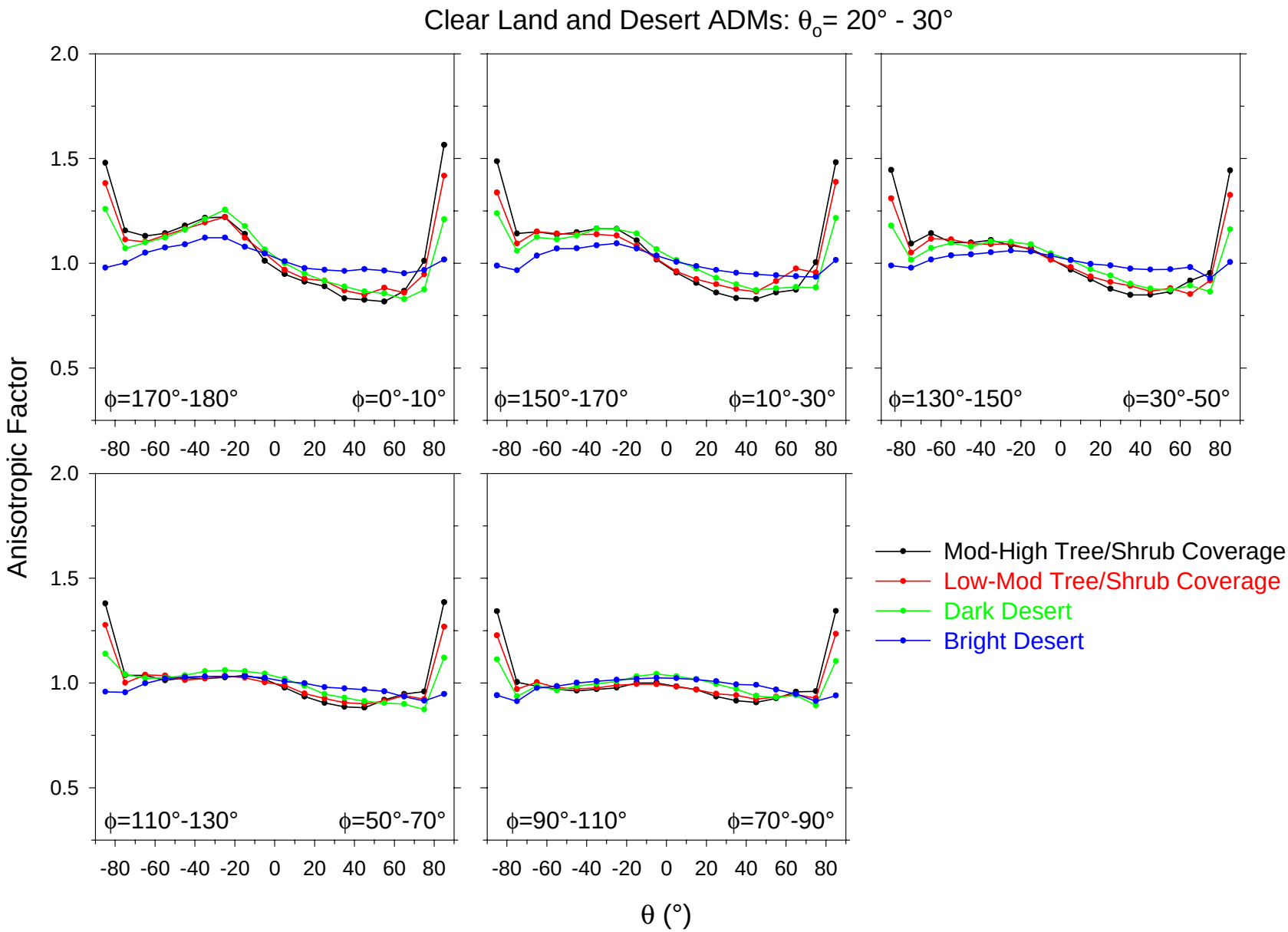


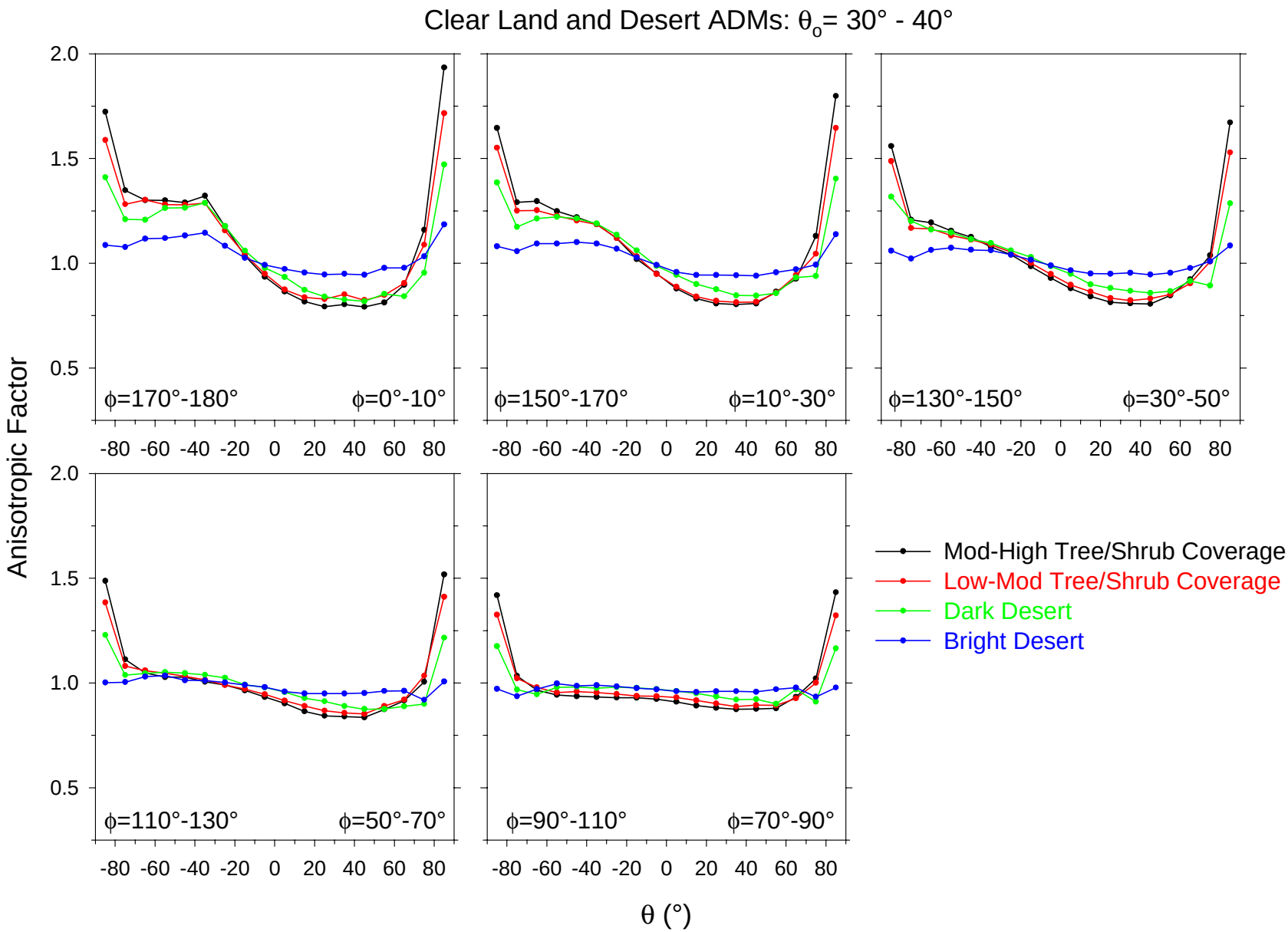
Clear Land and Desert ADMs: θ_o=30°-40°

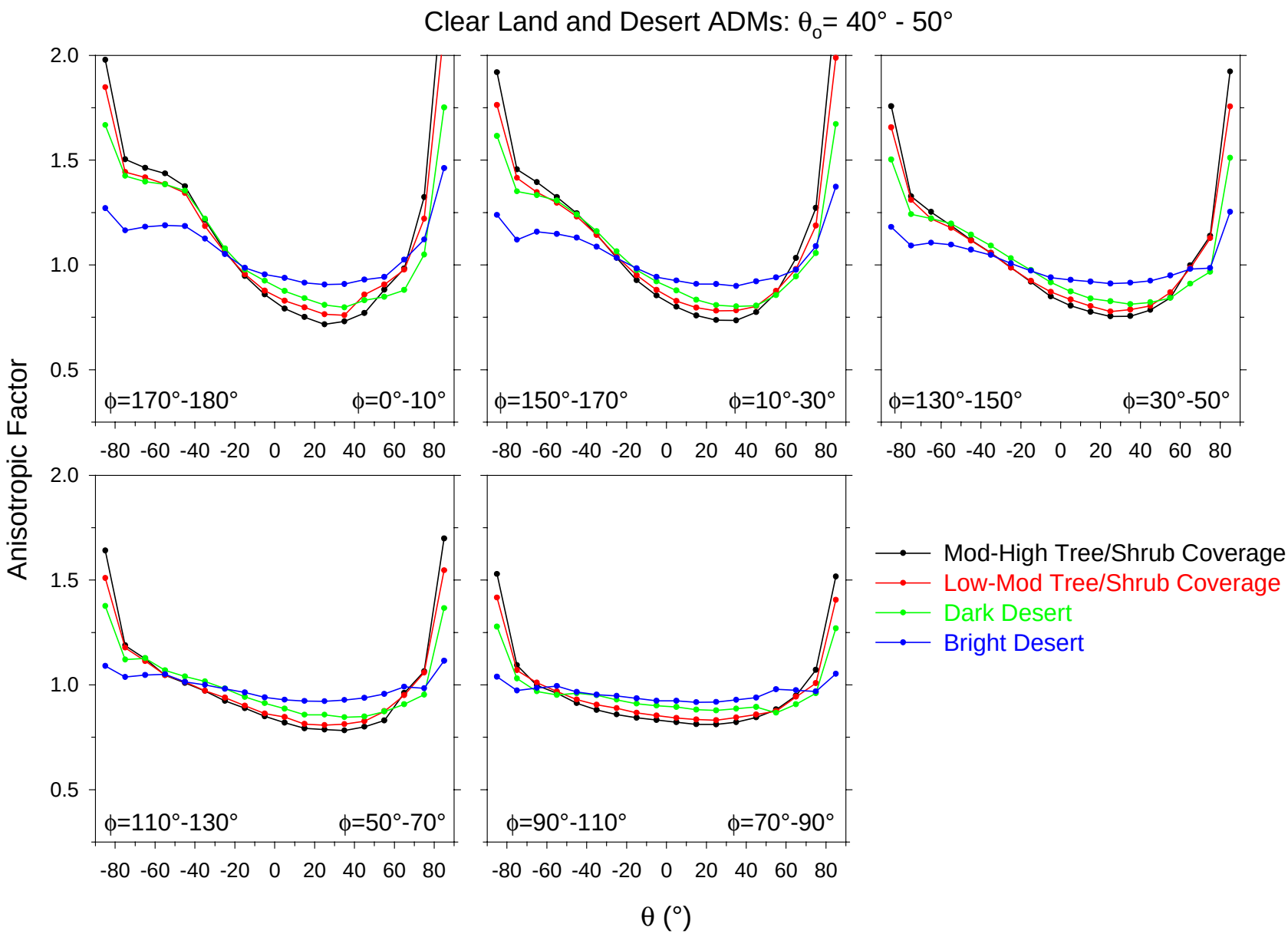


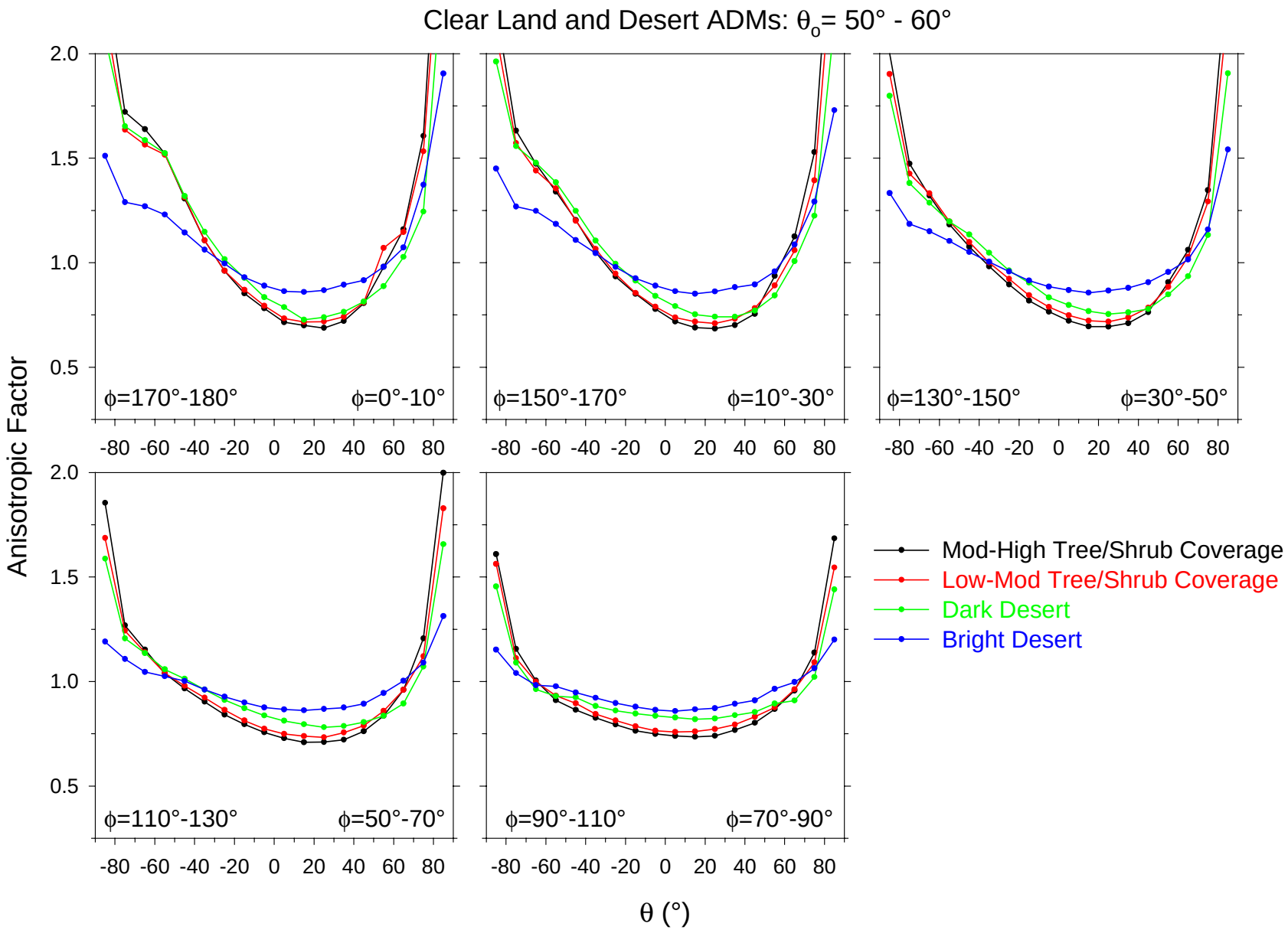

Clear Land and Desert ADMs: θo= 0° - 10°
Anisotropic Factor
2.0
1.5
1.0
0.5
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
-80 -60 -40 -20 0 20 40 60 80
θ (°)
Mod-High Tree/Shrub Coverage
Low-Mod Tree/Shrub Coverage
Dark Desert
Bright Desert

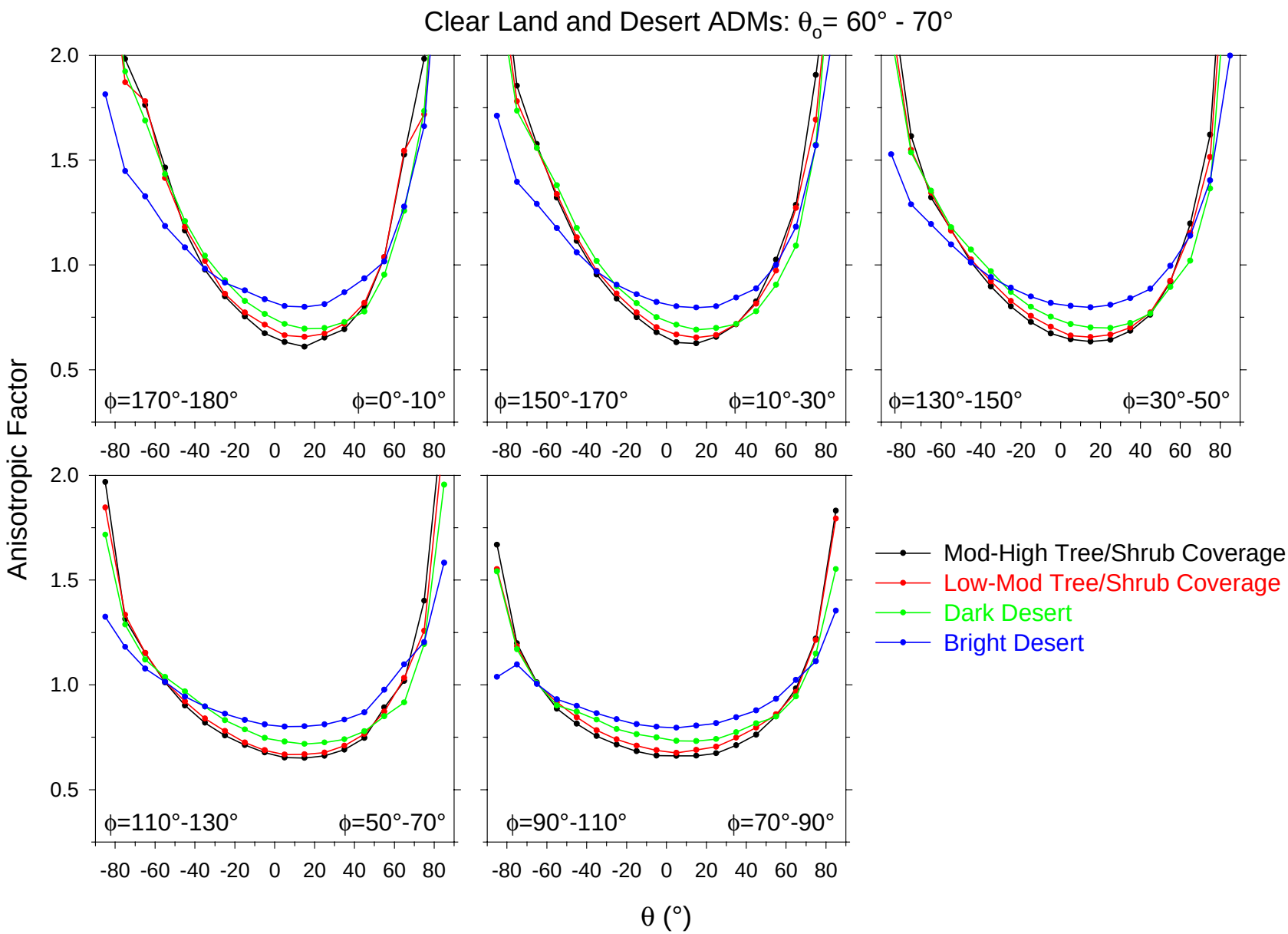

Clear Land and Desert ADMs: θo= 10° - 20°
Anisotropic Factor
2.0
1.5
1.0
0.5
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
-80 -60 -40 -20 0 20 40 60 80
θ (°)
Mod-High Tree/Shrub Coverage
Low-Mod Tree/Shrub Coverage
Dark Desert
Bright Desert

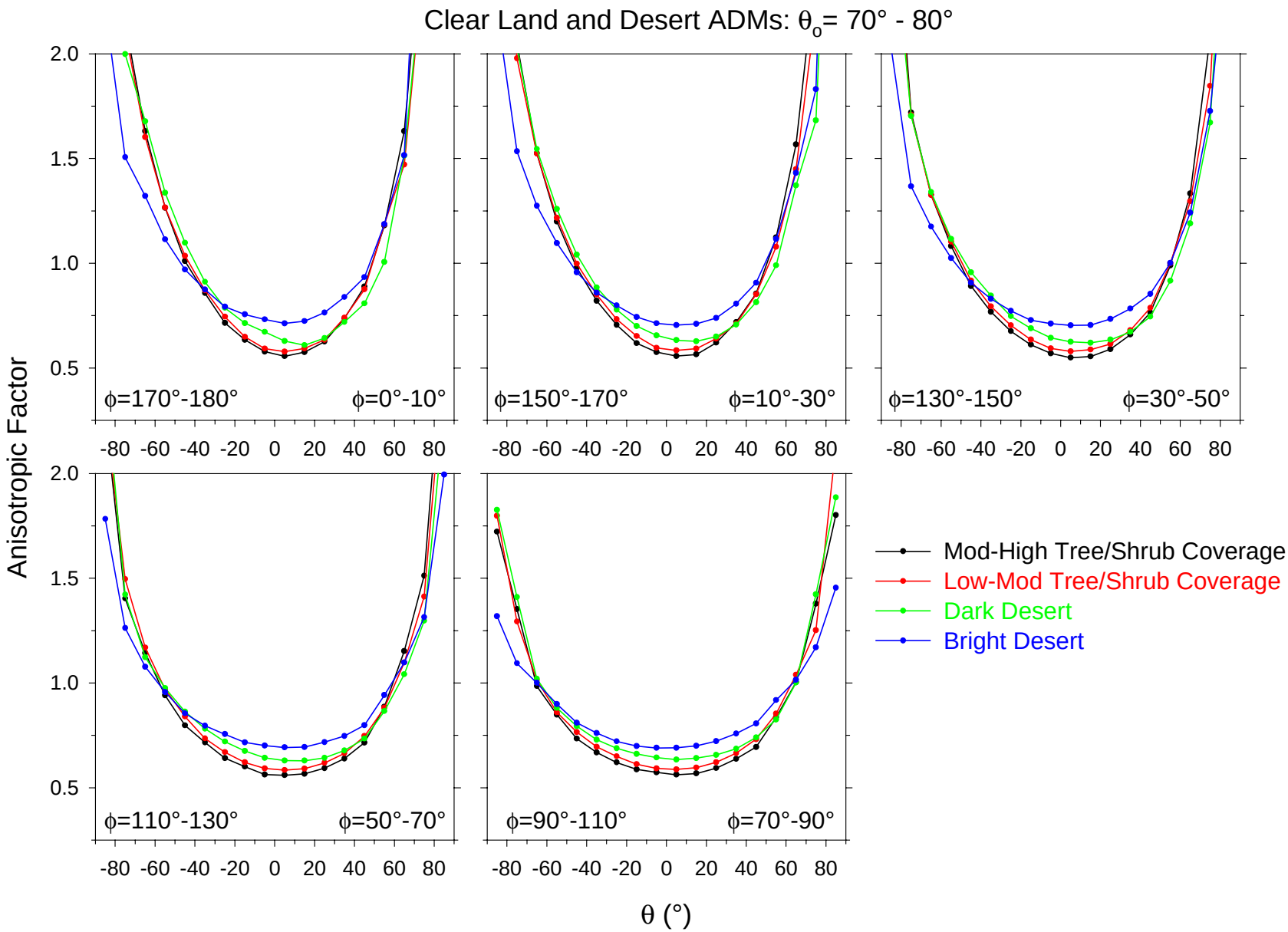

Clear Land and Desert ADMs: θo= 20° - 30°
Anisotropic Factor
2.0
1.5
1.0
0.5
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
-80 -60 -40 -20 0 20 40 60 80
θ (°)
Mod-High Tree/Shrub Coverage
Low-Mod Tree/Shrub Coverage
Dark Desert
Bright Desert

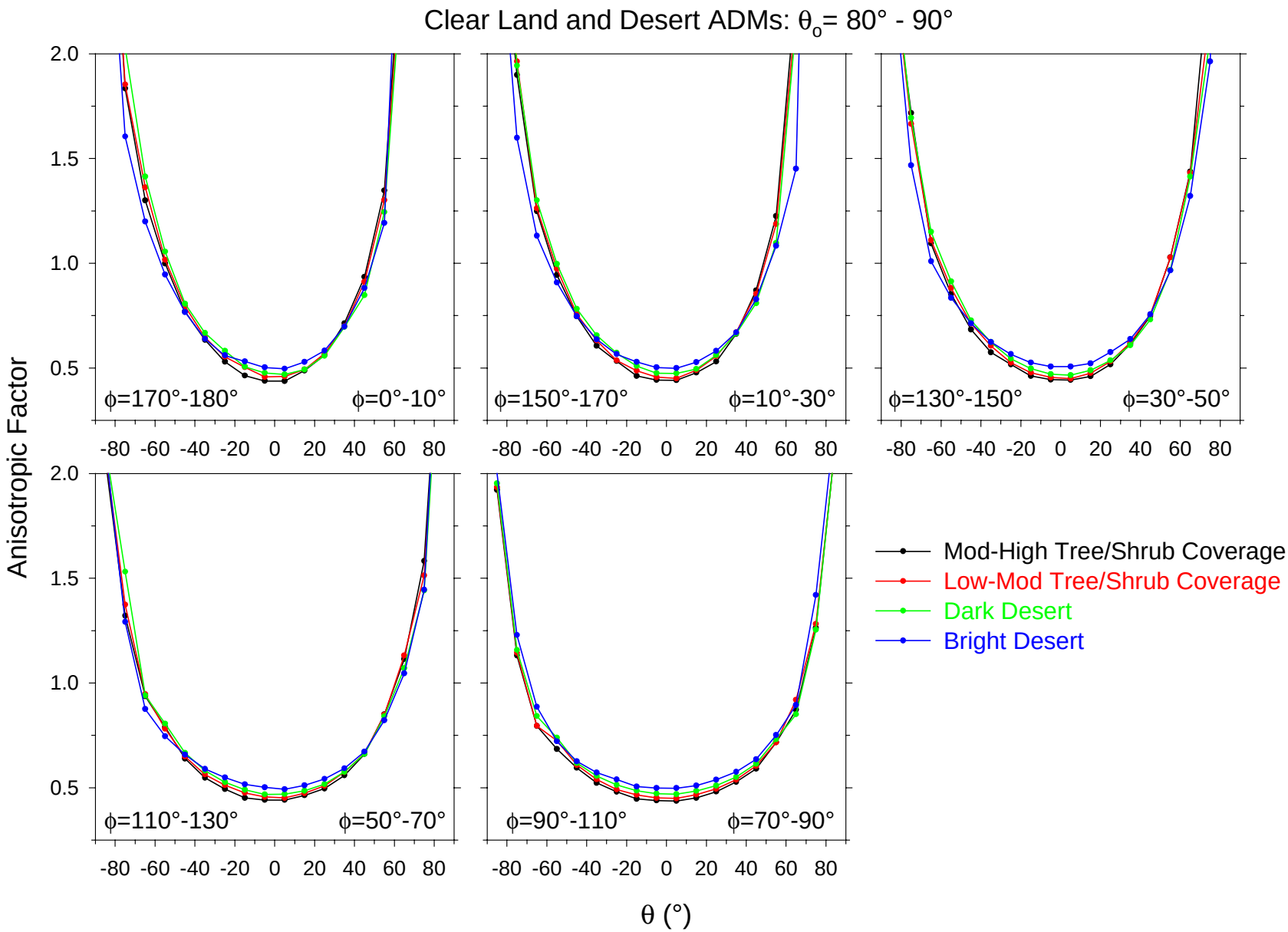

Clear Land and Desert ADMs: θo= 30° - 40°
Anisotropic Factor
2.0
1.5
1.0
0.5
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
-80 -60 -40 -20 0 20 40 60 80
θ (°)
Mod-High Tree/Shrub Coverage
Low-Mod Tree/Shrub Coverage
Dark Desert
Bright Desert


Clear Land and Desert ADMs: θo= 40° - 50°
Anisotropic Factor
2.0
1.5
1.0
0.5
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
-80 -60 -40 -20 0 20 40 60 80
θ (°)
Mod-High Tree/Shrub Coverage
Low-Mod Tree/Shrub Coverage
Dark Desert
Bright Desert


Clear Land and Desert ADMs: θo= 50° - 60°
Anisotropic Factor
2.0
1.5
1.0
0.5
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
-80 -60 -40 -20 0 20 40 60 80
θ (°)
Mod-High Tree/Shrub Coverage
Low-Mod Tree/Shrub Coverage
Dark Desert
Bright Desert


Clear Land and Desert ADMs: θo= 60° - 70°
Anisotropic Factor
2.0
1.5
1.0
0.5
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
-80 -60 -40 -20 0 20 40 60 80
θ (°)
Mod-High Tree/Shrub Coverage
Low-Mod Tree/Shrub Coverage
Dark Desert
Bright Desert


Clear Land and Desert ADMs: θo= 70° - 80°
Anisotropic Factor
2.0
1.5
1.0
0.5
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
-80 -60 -40 -20 0 20 40 60 80
θ (°)
Mod-High Tree/Shrub Coverage
Low-Mod Tree/Shrub Coverage
Dark Desert
Bright Desert


Clear Land and Desert ADMs: θo= 80° - 90°
Anisotropic Factor
2.0
1.5
1.0
0.5
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
-80 -60 -40 -20 0 20 40 60 80
θ (°)
Mod-High Tree/Shrub Coverage
Low-Mod Tree/Shrub Coverage
Dark Desert
Bright Desert

ADMs For Clouds Over Ocean

- 2 Cloud Phases:

  Liquid Water : Avg Phase over CERES footprint ≤ 1.5

  Ice : Avg Phase over CERES footprint > 1.5

- 12 Cloud Fraction Intervals (%):

  0.1-10; 10-20; 20-30; 30-40; 40-50; 50-60; 60-70; 70-80; 80-90; 90-95; 95-99.9; 99.9-100

- 14 “Adjusted” Cloud Optical Depth Intervals:

  0.01-1; 1-2.5; 2.5-5; 5-7.5; 7.5-10; 10-12.5; 12.5-15; 15-17.5; 17.5-20; 20-25; 25-30; 30-40; 40-50; >50;

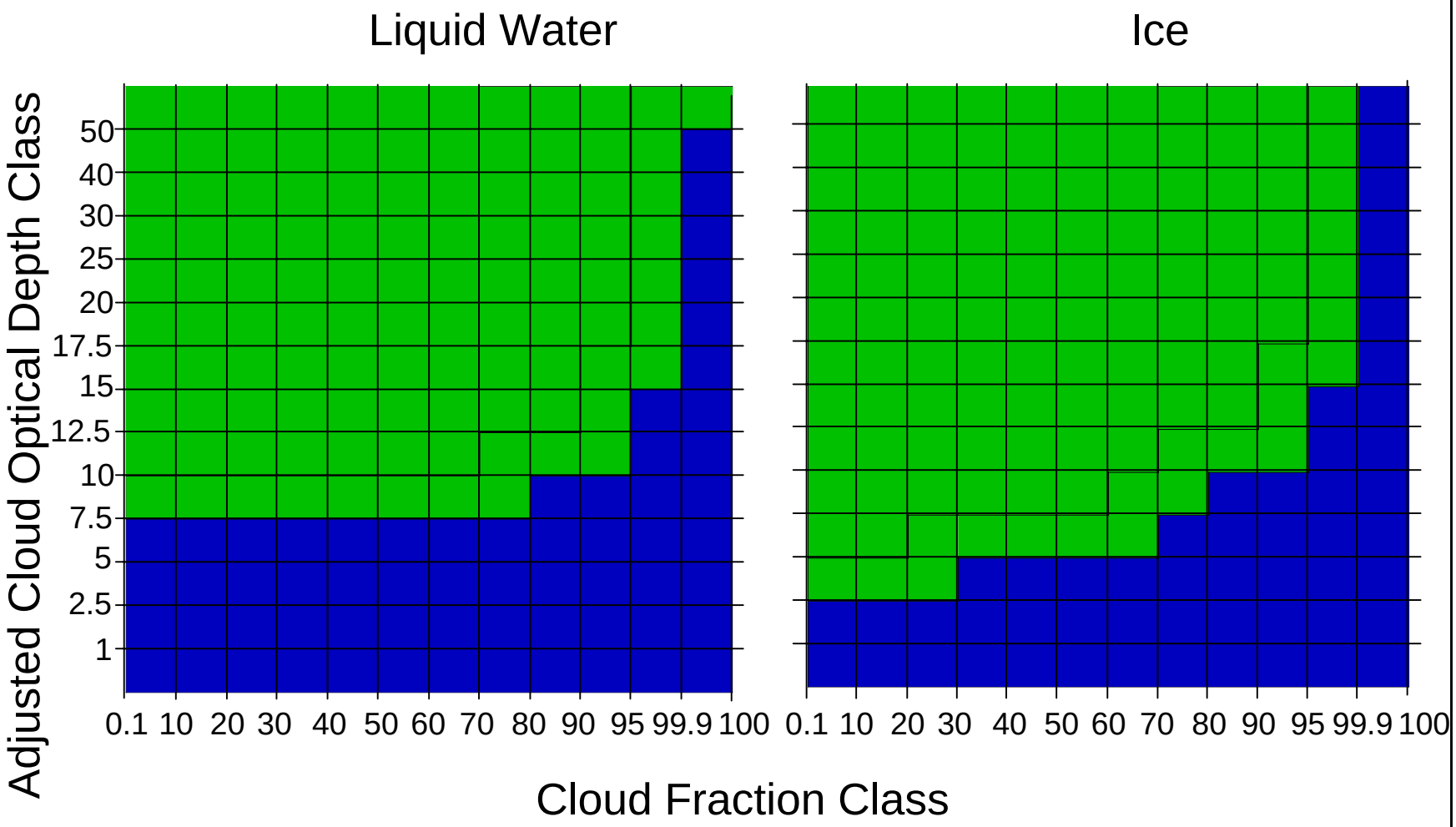
Adjustment of Cloud Optical Depth Retrievals

- Apply "adjustment" to 1D retrievals at VIRS pixel scale that forces ensemble cloud optical depth distributions to be self-consistent in all viewing geometries.
  => Assumes true optical depth does not depend on sun-earth-satellite viewing geometry.

- Requires knowledge of a reference cloud optical depth distribution representative of "truth" (e.g. from specific angle/other source).

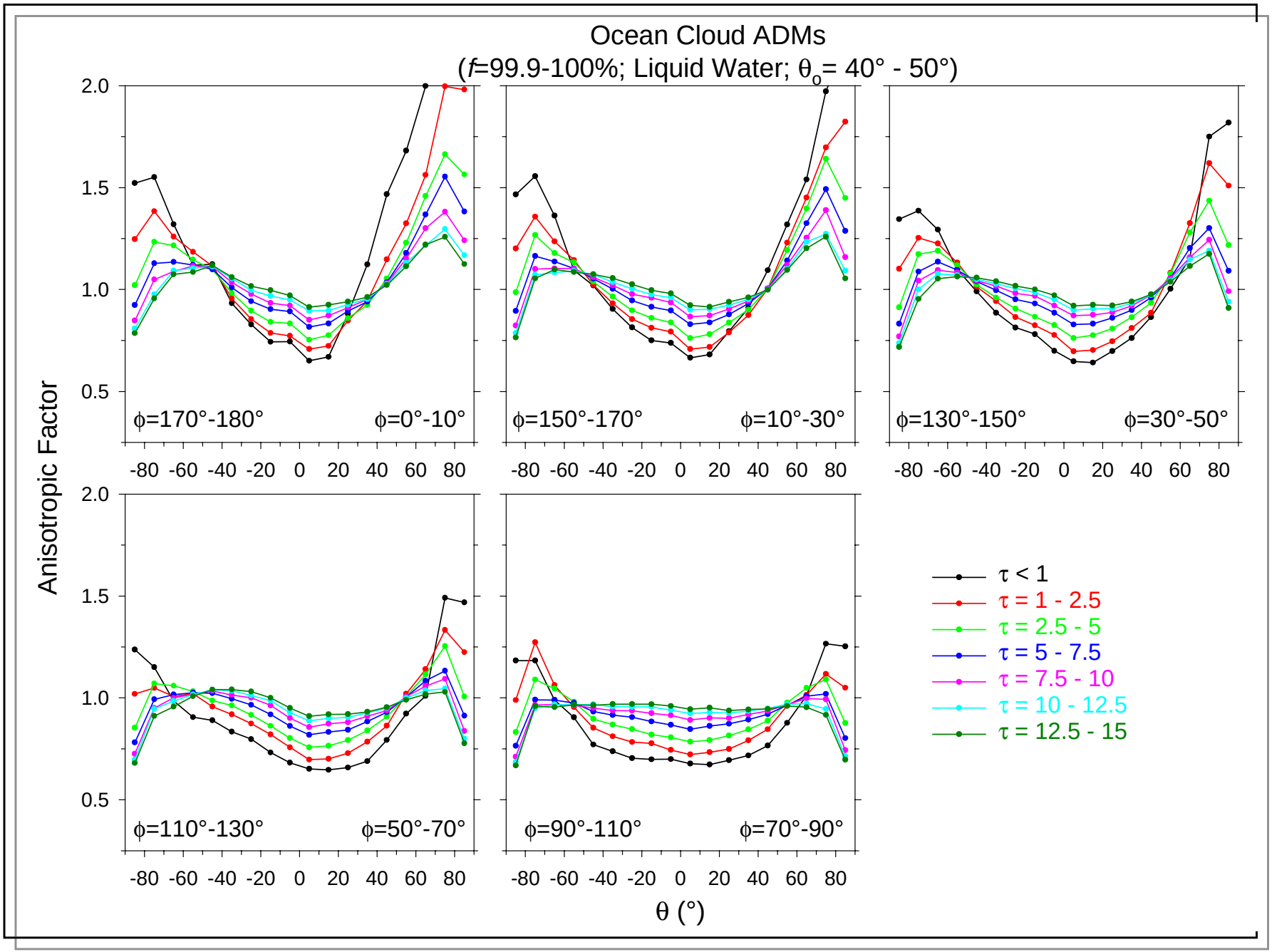
- Attempts to "correct" for potential biases in retrieval scheme only—i.e. it does not account for possible biases due to variable imager/CERES spatial resolution with angle.

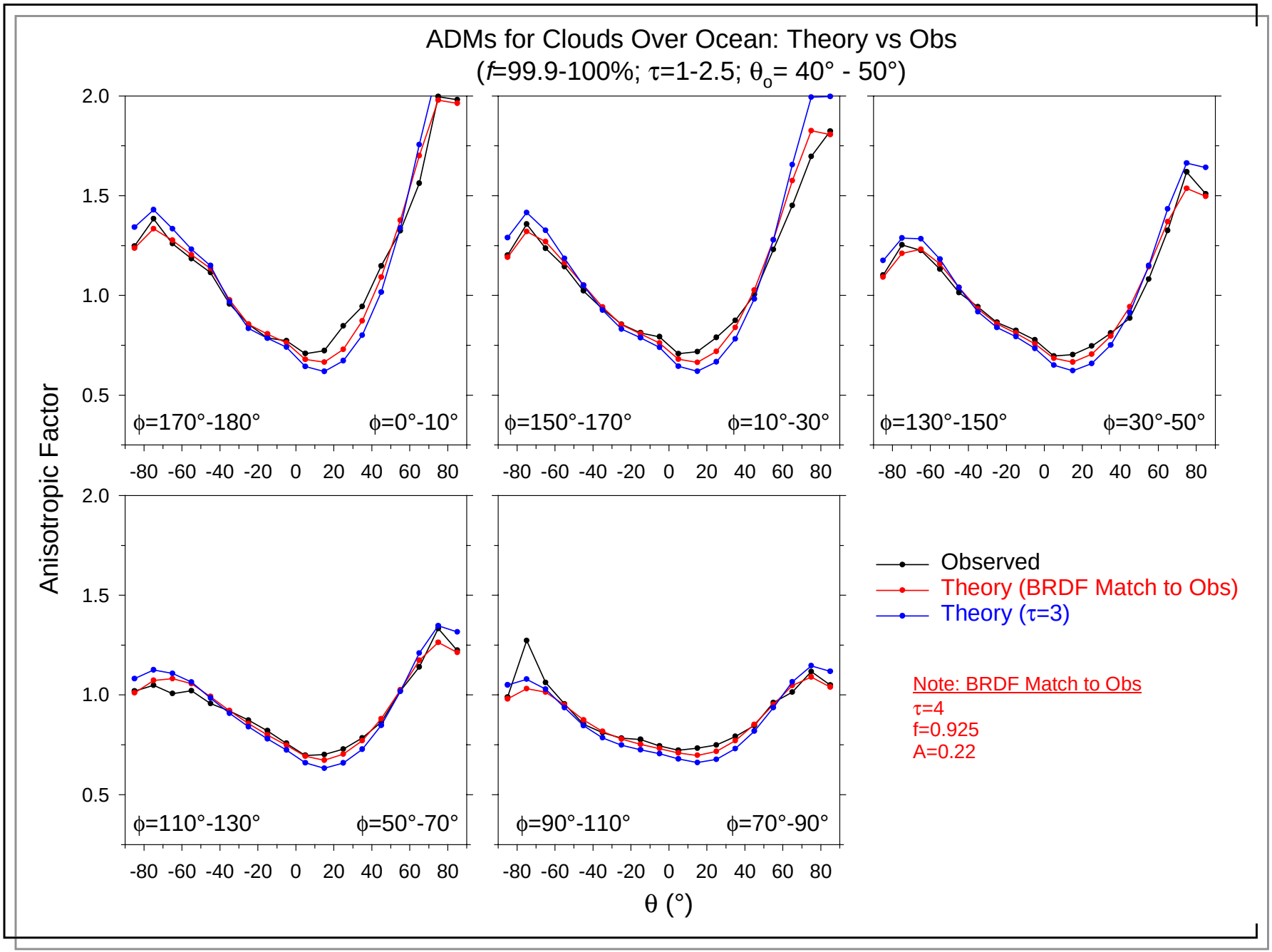
Sampling of Cloud Classes (θ_o=40°-50°)

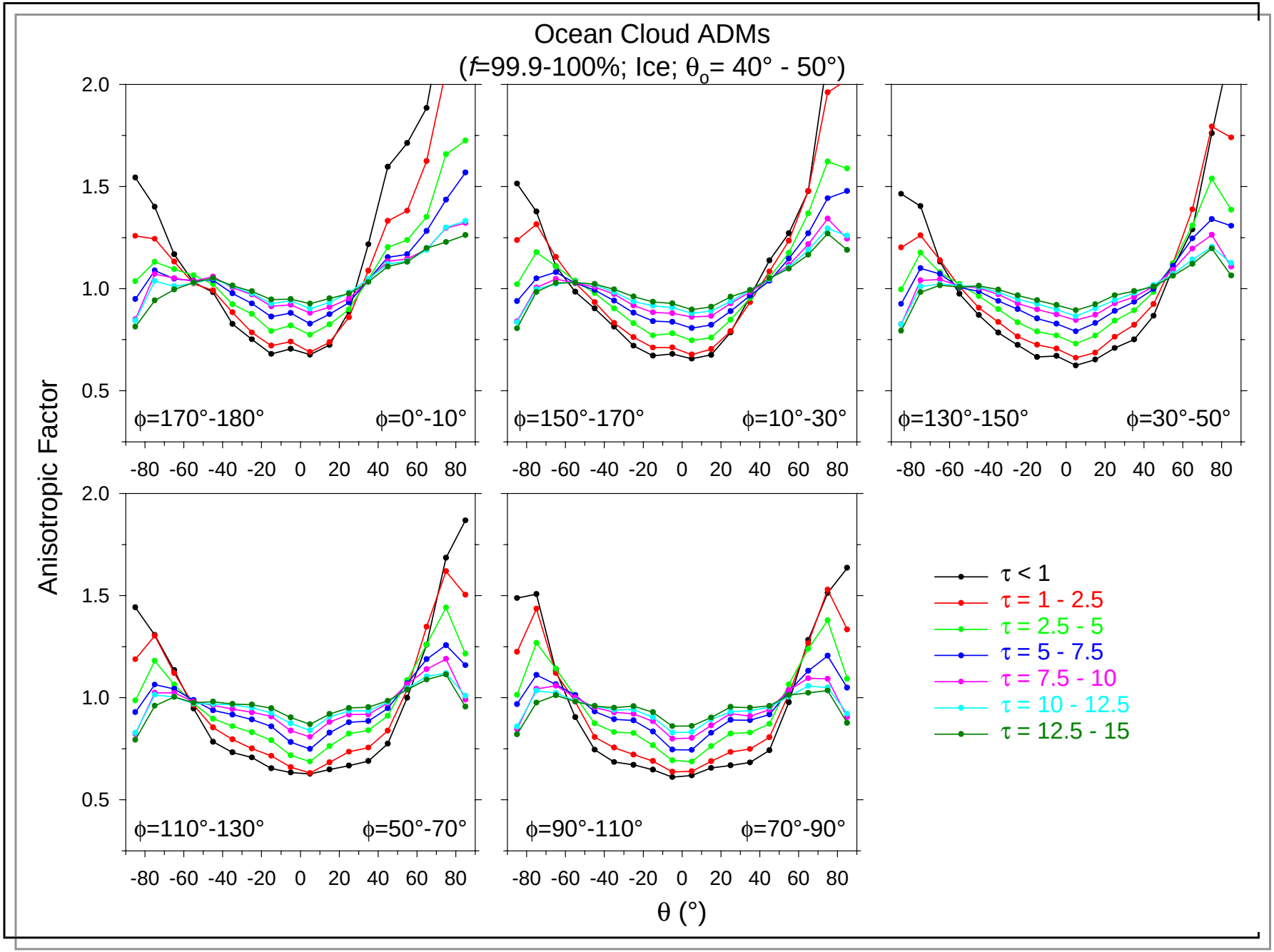


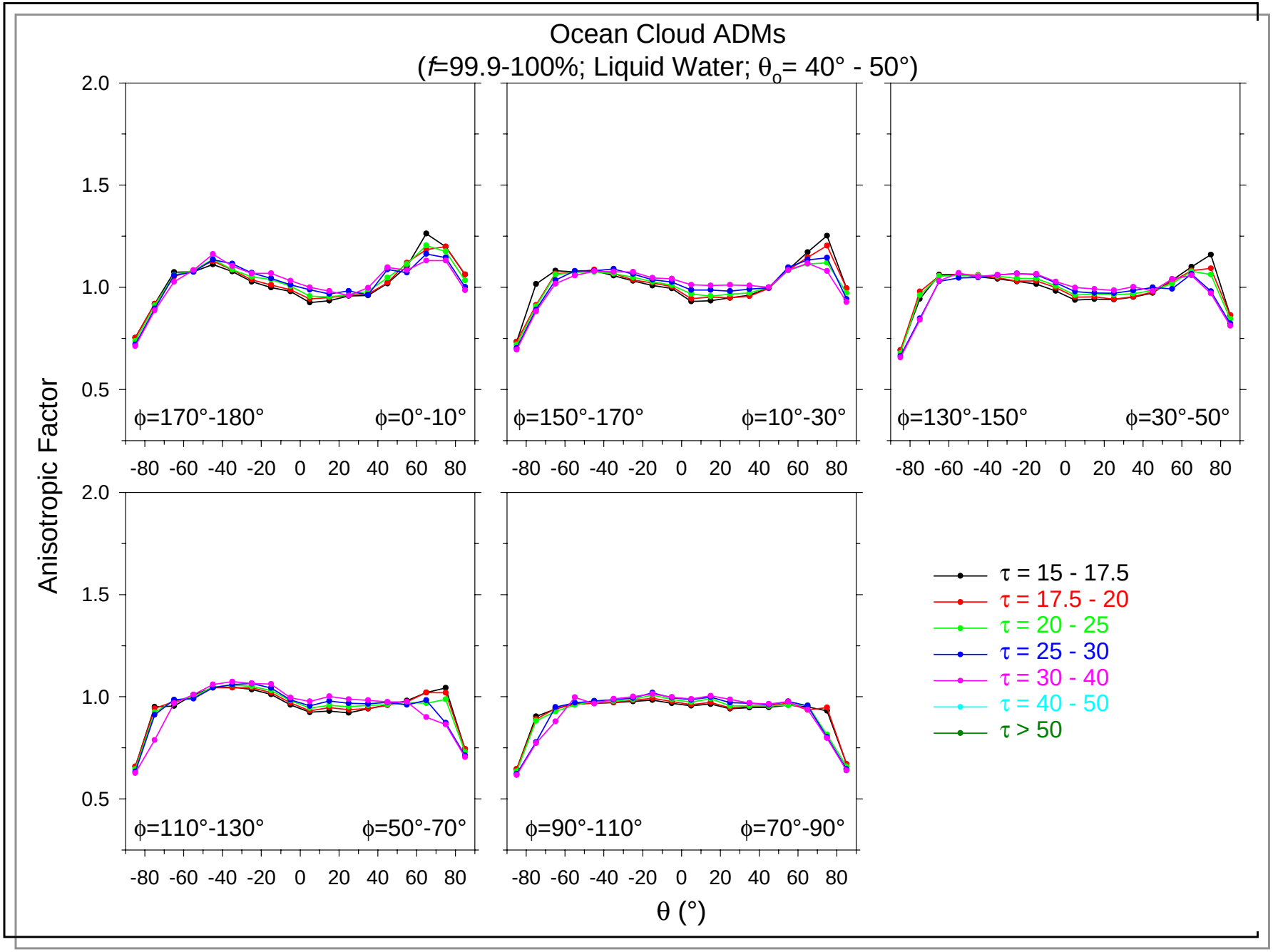
total: 62 / 168

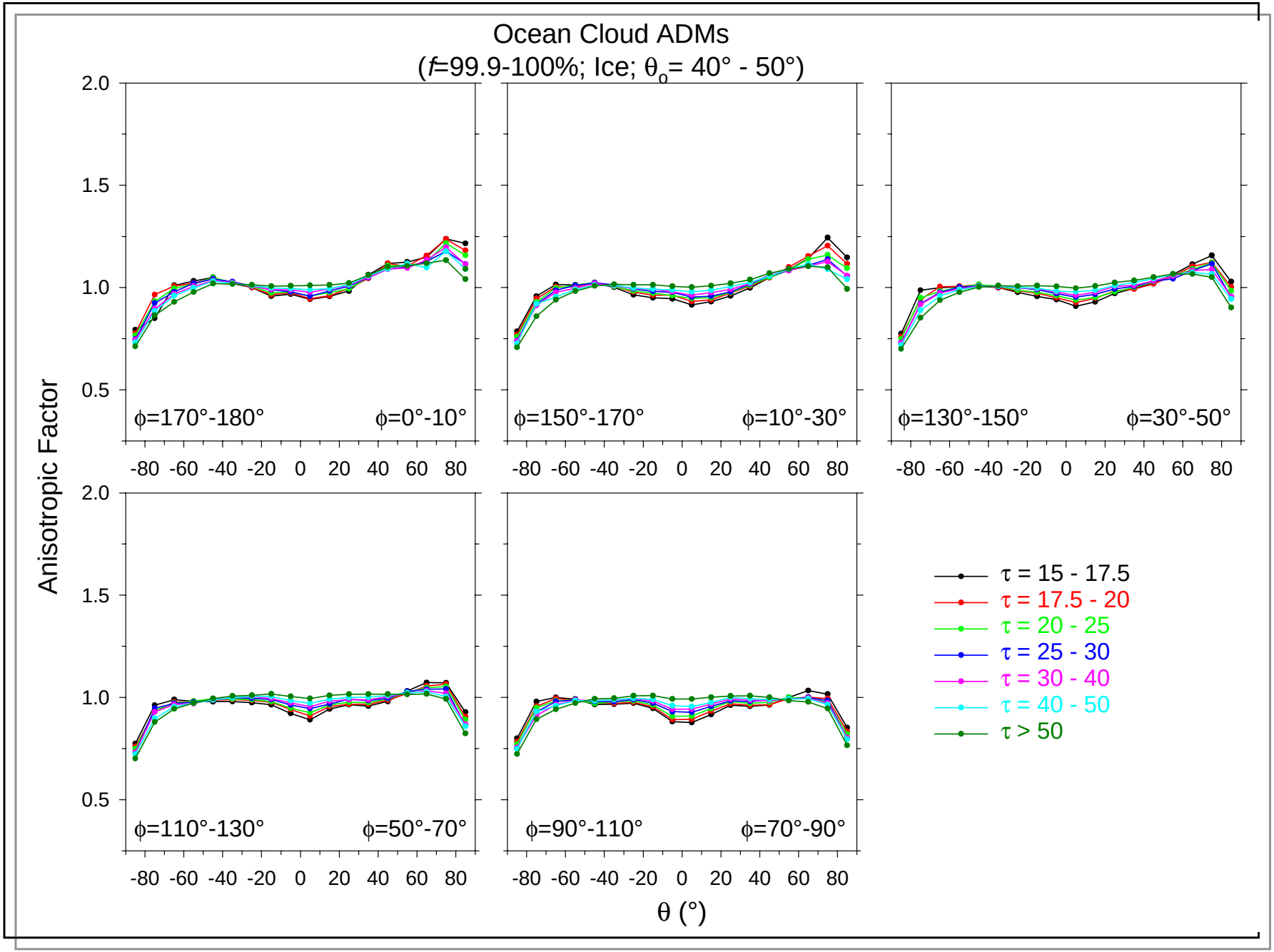
total: 53 / 168


Ocean Cloud ADMs
(f=99.9-100%; Liquid Water; θo= 40° - 50°)
Anisotropic Factor
θ (°)
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
τ < 1
τ = 1 - 2.5
τ = 2.5 - 5
τ = 5 - 7.5
τ = 7.5 - 10
τ = 10 - 12.5
τ = 12.5 - 15


ADMs for Clouds Over Ocean: Theory vs Obs
(f=99.9-100%; τ=1-2.5; θo= 40° - 50°)
Anisotropic Factor
2.0
1.5
1.0
0.5
-80 -60 -40 -20 0 20 40 60 80
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
θ (°)
Observed
Theory (BRDF Match to Obs)
Theory (τ=3)
Note: BRDF Match to Obs
τ=4
f=0.925
A=0.22


Ocean Cloud ADMs
(f=99.9-100%; Ice; θo= 40° - 50°)
Anisotropic Factor
θ (°)
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
τ < 1
τ = 1 - 2.5
τ = 2.5 - 5
τ = 5 - 7.5
τ = 7.5 - 10
τ = 10 - 12.5
τ = 12.5 - 15


Ocean Cloud ADMs
(f=99.9-100%; Liquid Water; θo= 40° - 50°)
Anisotropic Factor
2.0
1.5
1.0
0.5
-80 -60 -40 -20 0 20 40 60 80
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
θ (°)
τ = 15 - 17.5
τ = 17.5 - 20
τ = 20 - 25
τ = 25 - 30
τ = 30 - 40
τ = 40 - 50
τ > 50


Ocean Cloud ADMs
(f=99.9-100%; Ice; θo= 40° - 50°)
Anisotropic Factor
2.0
1.5
1.0
0.5
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
-80 -60 -40 -20 0 20 40 60 80
θ (°)
τ = 15 - 17.5
τ = 17.5 - 20
τ = 20 - 25
τ = 25 - 30
τ = 30 - 40
τ = 40 - 50
τ > 50

ADMs For Clouds Over Land

- 4 Surface Types:
  - Mod-to-High Tree/Shrub Coverage
  - Low-to-Mod Tree/Shrub Coverage
  - Dark Desert
  - Bright Desert

- 2 Cloud Phases:

  Liquid Water : Avg Phase over CERES footprint ≤ 1.5

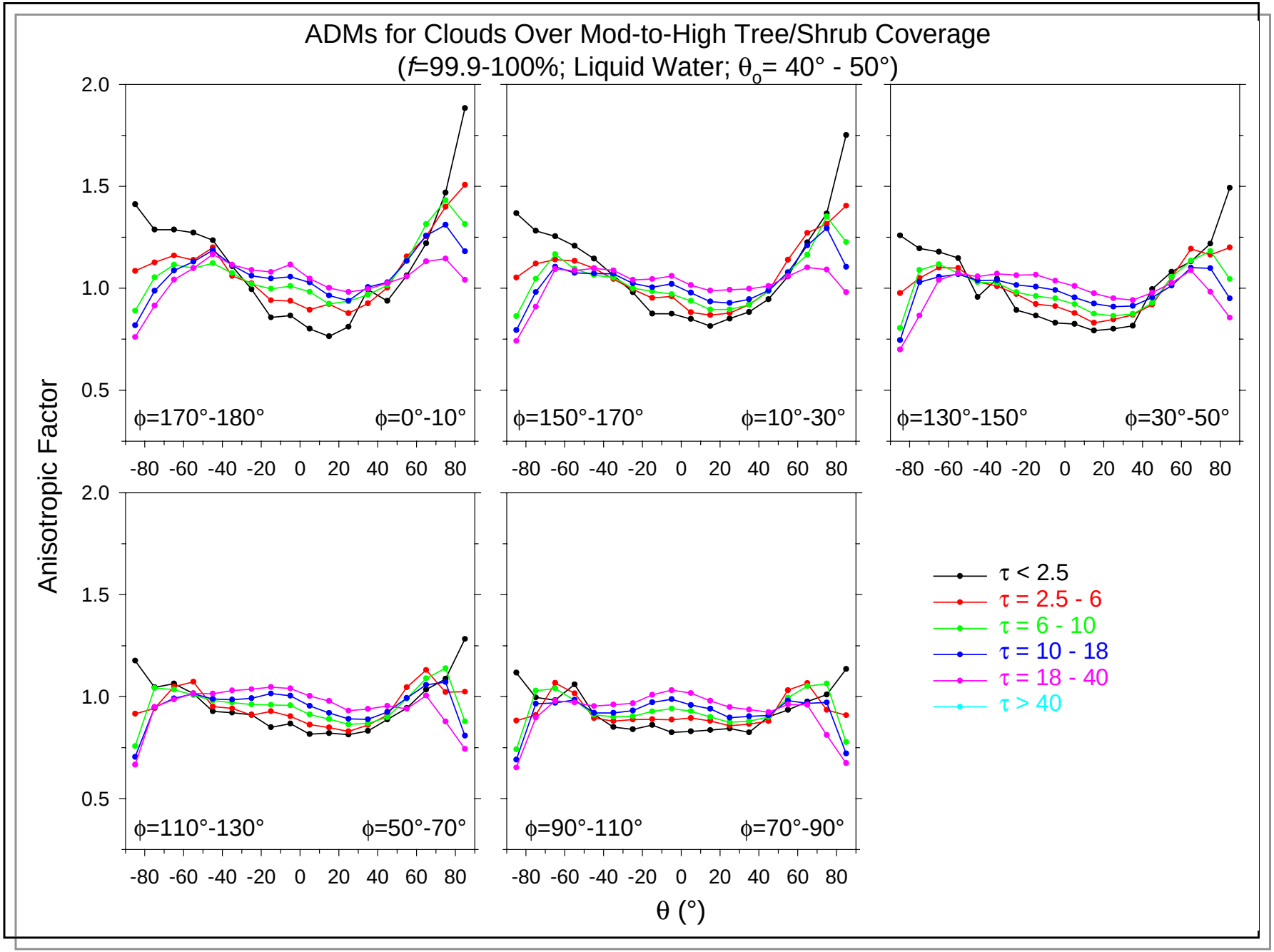
  Ice : Avg Phase over CERES footprint > 1.5

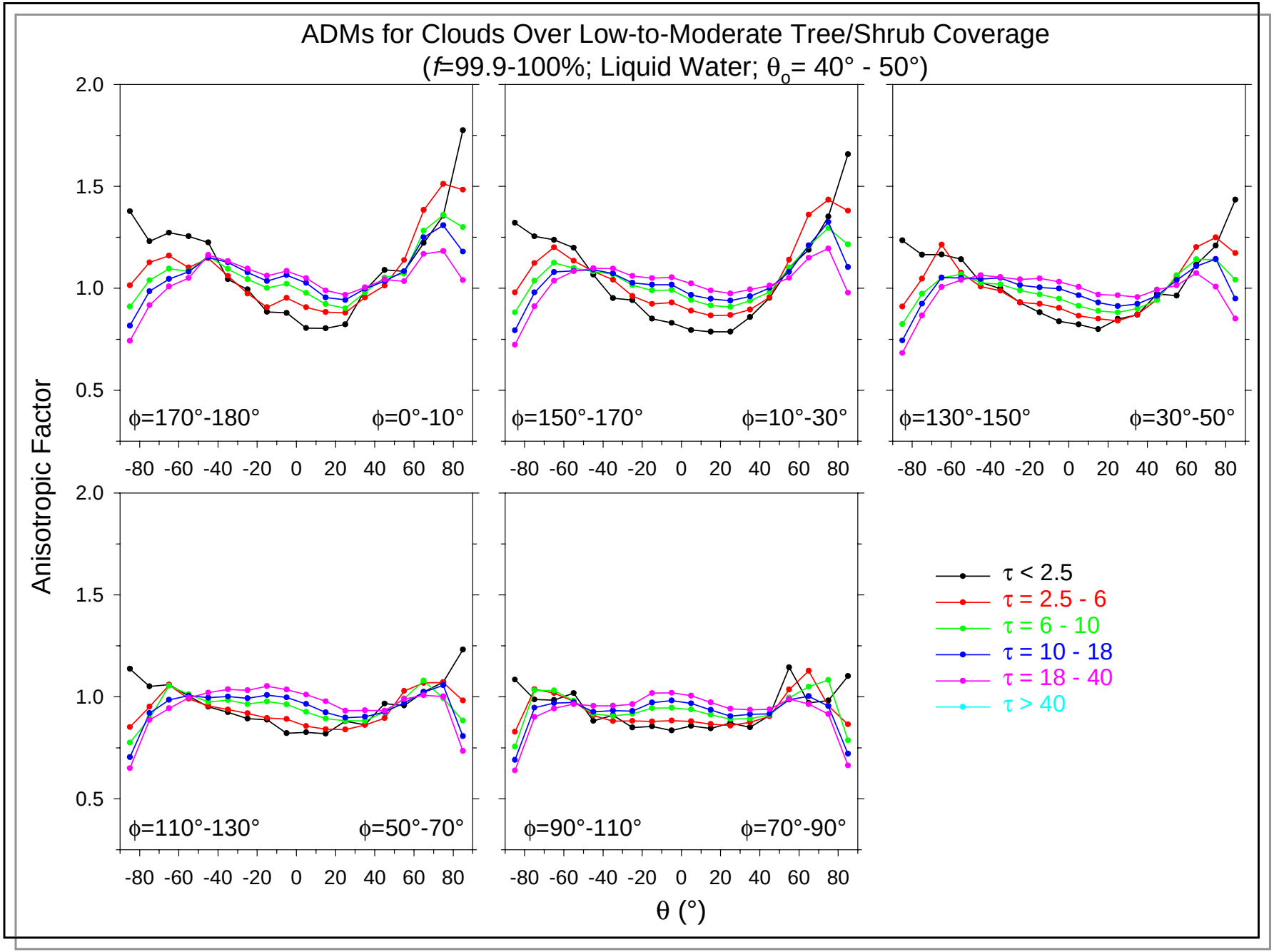
- 5 Cloud Fraction Intervals (%):

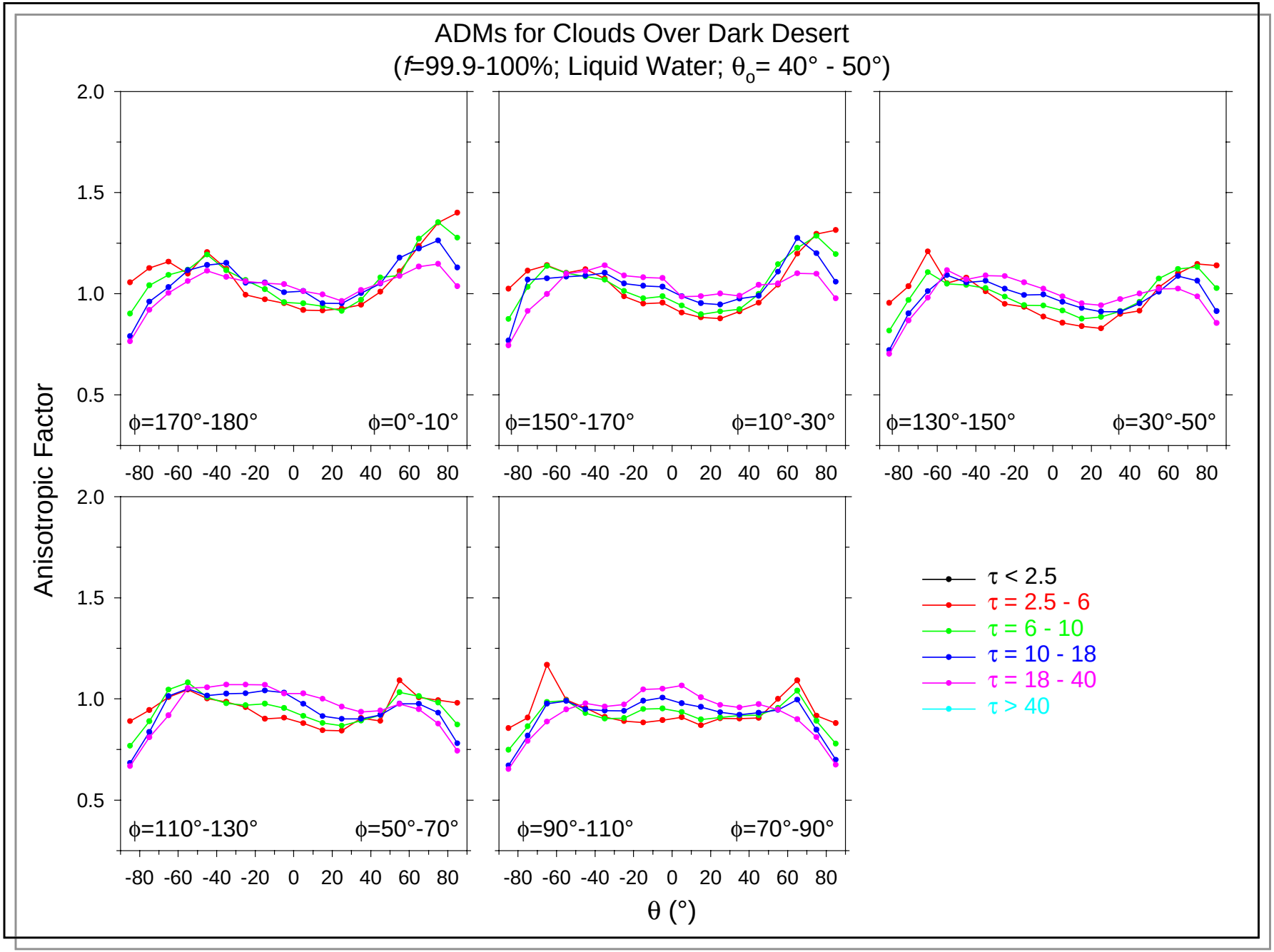
  0.1-25; 25-50; 50-75; 75-99.9; 99.9-100

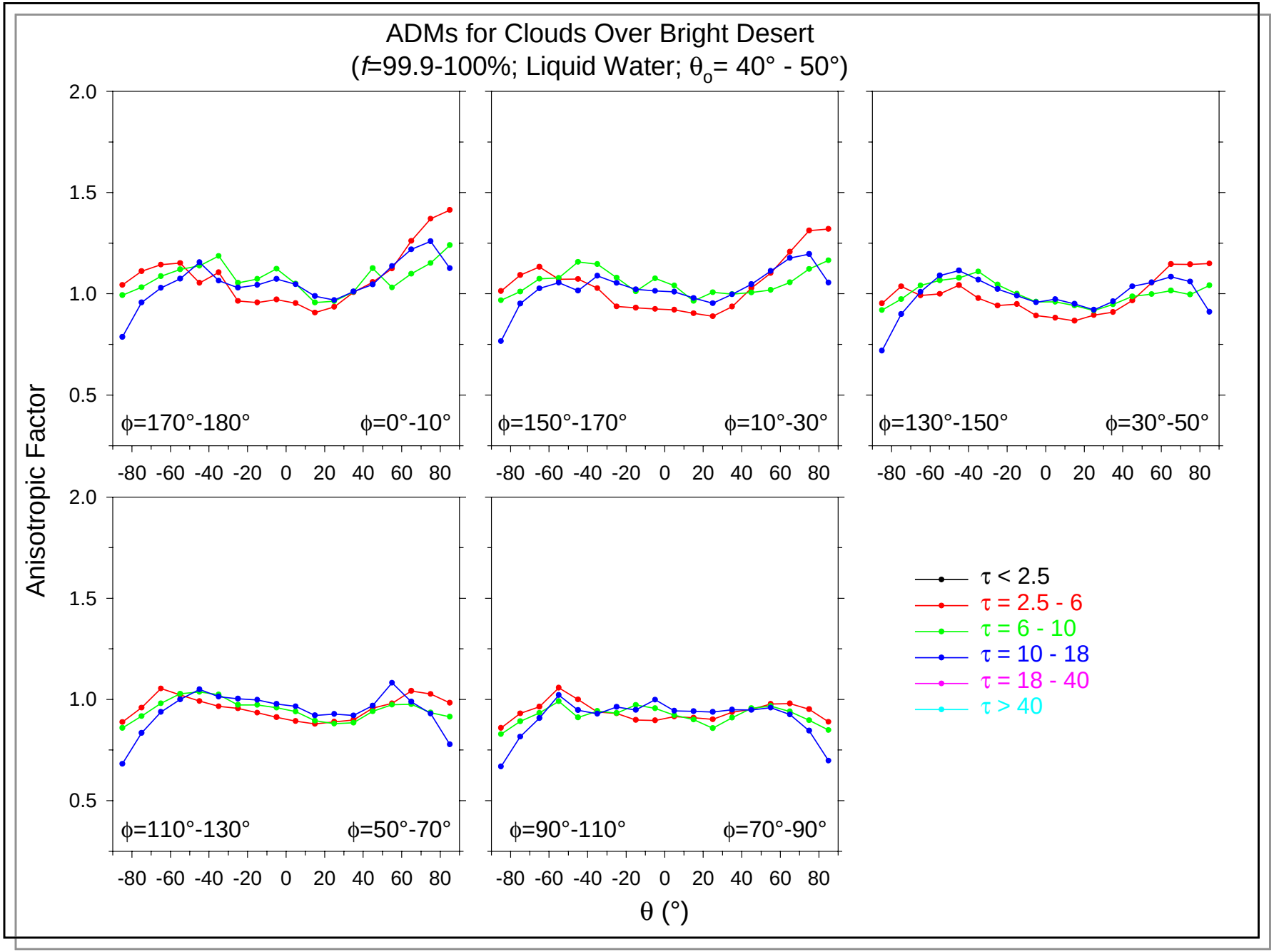
- 6 “Adjusted” Cloud Optical Depth Intervals:

  0.01-2.5; 2.5-6; 6-10; 10-18; 18-40; >50


ADMs for Clouds Over Mod-to-High Tree/Shrub Coverage
(f=99.9-100%; Liquid Water; θo= 40° - 50°)
Anisotropic Factor
θ (°)
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
τ < 2.5
τ = 2.5 - 6
τ = 6 - 10
τ = 10 - 18
τ = 18 - 40
τ > 40


ADMs for Clouds Over Low-to-Moderate Tree/Shrub Coverage
(f=99.9-100%; Liquid Water; θo= 40° - 50°)
Anisotropic Factor
θ (°)
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
τ < 2.5
τ = 2.5 - 6
τ = 6 - 10
τ = 10 - 18
τ = 18 - 40
τ > 40


ADMs for Clouds Over Dark Desert
(f=99.9-100%; Liquid Water; θo= 40° - 50°)
Anisotropic Factor
2.0
1.5
1.0
0.5
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
-80 -60 -40 -20 0 20 40 60 80
θ (°)
τ < 2.5
τ = 2.5 - 6
τ = 6 - 10
τ = 10 - 18
τ = 18 - 40
τ > 40


ADMs for Clouds Over Bright Desert
(f=99.9-100%; Liquid Water; θo= 40° - 50°)
Anisotropic Factor
2.0
1.5
1.0
0.5
-80 -60 -40 -20 0 20 40 60 80
ϕ=170°-180°
ϕ=0°-10°
ϕ=150°-170°
ϕ=10°-30°
ϕ=130°-150°
ϕ=30°-50°
ϕ=110°-130°
ϕ=50°-70°
ϕ=90°-110°
ϕ=70°-90°
θ (°)
τ < 2.5
τ = 2.5 - 6
τ = 6 - 10
τ = 10 - 18
τ = 18 - 40
τ > 40

ADMs Over Snow

- CERES-TRMM:
  - Insufficient sampling to develop empirical models
  - Rather theoretical models using DISORT will be developed with parameterized snow surface BRDF

- CERES-Terra:
  - Models will be empirical. Too early to say what (if any) scene type stratification will be made.

ADM Validation Plans

- Flux Viewing Zenith Angle Dependence
  - Does all-sky flux depend on viewing geometry?
  - Flux vs cloud property dependencies: do we get consistent results from different viewing geometries?

- Regional Direct Integration Checks
  - Are all-sky regional mean fluxes from ADMs consistent with fluxes inferred by direct integration of mean radiances?

- Along-Track Flux Consistency Checks
  - Are instantaneous clear-sky fluxes consistent from different viewing geometries?

TOA Flux Production Schedule

1. Prior to May 2001 CERES Science Team Meeting

- Finalize CERES-TRMM SW, LW and WN ADMs.
- Provide near-final version of ADM production code that uses CERES-TRMM ADMs.
- Make preliminary SSFs with new TOA fluxes available (e.g. full SSFs for one month; one or more months over validation regions).
- Continue validation of new TOA fluxes.

2. August 2001

- Complete SSF Edition 2 Quality Summary.
- Begin production of SSF Edition 2.