Polarization correction algorithm using simulated Stokes parameters for GEMS and TEMPO

Ukkyo Jeong[1,2], Xiong Liu[3], Jhoon Kim[4], Gonzalo Abad[3], James Lasnik[5], David Edwards[6], Kelly Chance[3], Robert Spurr[7]

[1]UMD ESSIC [2]NASA GSFC [3]Harvard SAO
[4]Yonsei University [5]BATC [6]NCAR
[7]RT solution inc.

Backgrounds

- **Due to mirrors, gratings, and prisms, the radiometric response function depends on the polarization of the incoming light (e.g. Schutgens and Stammes, 2003).**
- **Nadir-looking space-borne spectrometers have two options for treating the atmospheric polarization of the incoming light (Calies et al. 2000).**

1. **Destroy the polarization information by scrambling (TOMS, SBUV, OMI)**
2. **Measure the polarization with sufficient accuracy to correct for the polarization dependence of the instrument (SCIAMACHY, GOME)**

→ **A correct radiometric calibration requires knowledge of both the polarization properties of the instrument (measured before launch) and the actual polarization of the incoming light (measured for each observed pixel)**

(e.g. Schutgens and Stammes, 2003).

TEMPO and GEMS will use wave plate to decrease polarization sensitivity, and planning to develop additional polarization correction algorithm using the simulated Stokes' parameters instead of the measurements in approach 2.

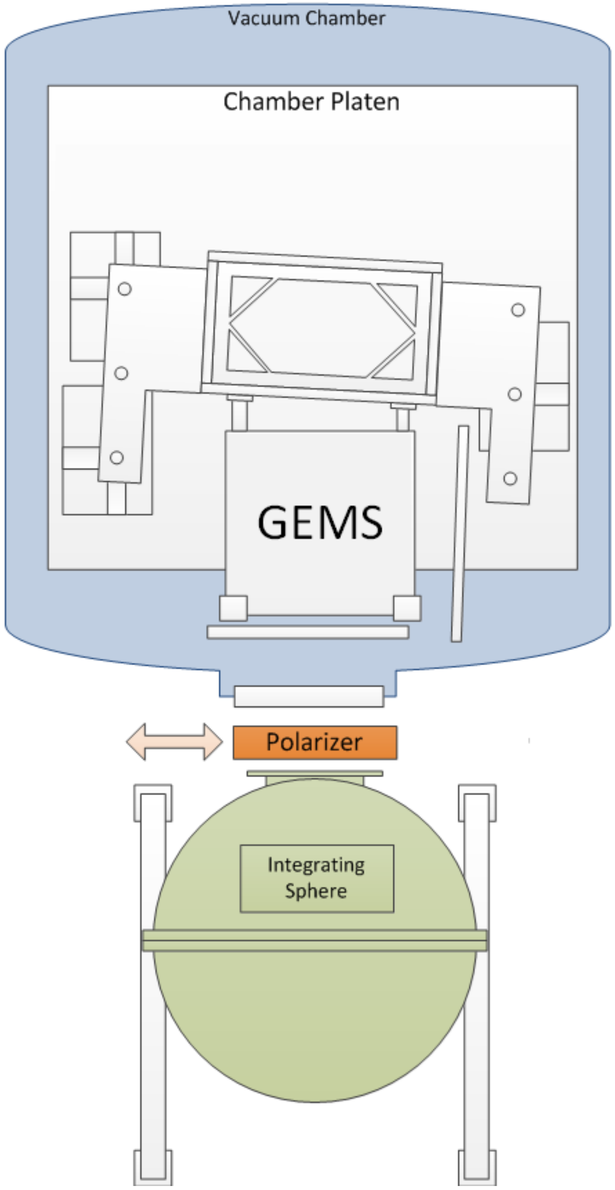
GEMS/TEMPO Radiometric Calibration and Polarization Test Setup (courtesy of BATC)

Calibration Test Station (CATS)

The CATS Test Setup Verifies/Characterizes:
- Radiometric Calibration / Accuracy
- Linear Polarization Sensitivity (LPS)

Radiometric Calibration Test Method
- The GEMS instrument is illuminated by a NIST-traceable integrating sphere during T-Vac testing
  - The calibration of three NIST FEL lamps is transferred to the sphere using a redundant, 2-step process
- GEMS is calibrated in a flight-like environment using the flight electronics

Polarization (LPS) Test Method
- **A wire-grid polarizer is placed in the illumination path between the integrating sphere and GEMS instrument**
- **The plane of polarization is varied by rotating the polarizer (720 °)**



Polarization sensitivity and correction method
(Sun and Xiong, 2007)

$$I' = hI\{1 + fa\cos[2(\phi - \chi)]\}$$

$$f = \frac{I_{max} - I_{min}}{I}$$

I' : Intensity reaching the CCD arrays
h : Transmittance
I : Intensity reaching the diffuser
a : Degree of polarization
ϕ : Angle of maximum transmission
χ : Phase angle of polarization w.r.t. instrument's reference plane
I_{max} : maximum transmission
I_{min} : minimum transmission (assume it's perpendicular to I_{max})

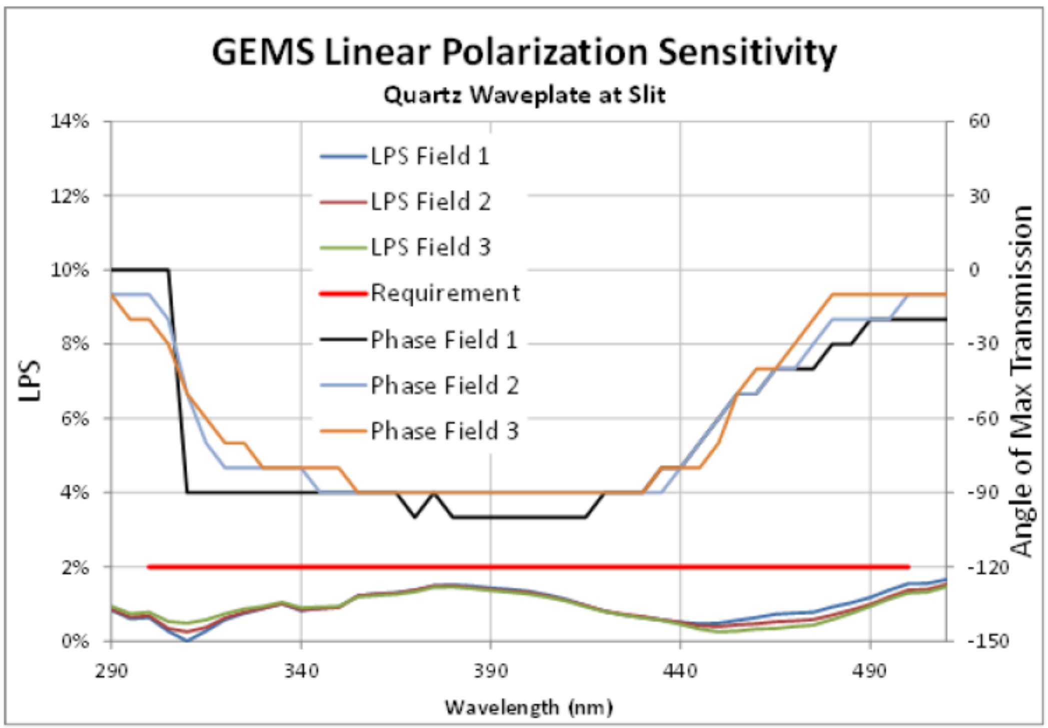


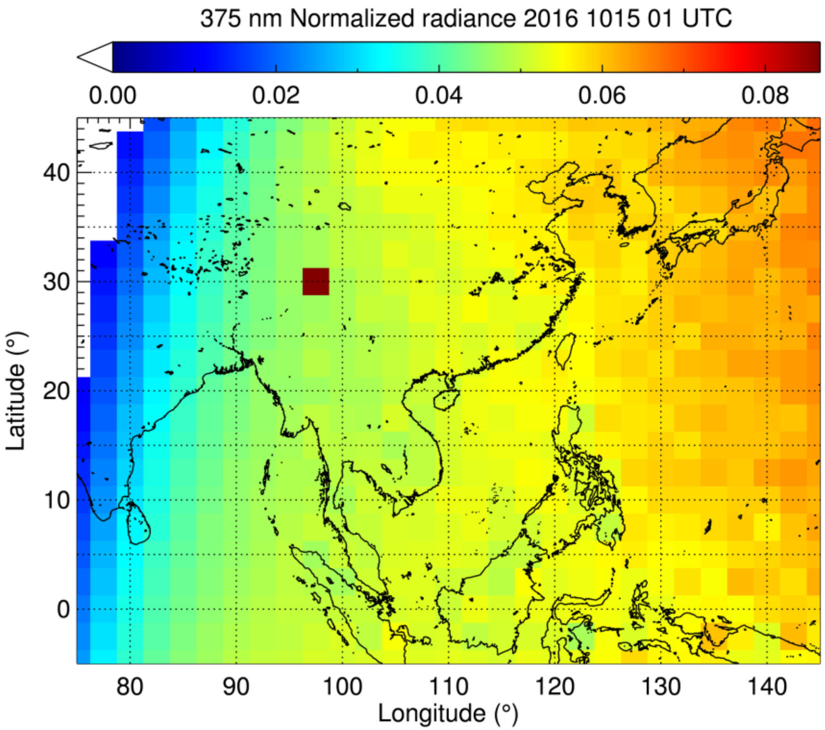
Figure 1: GEMS LPS and Phase over GEMS Spectral Range

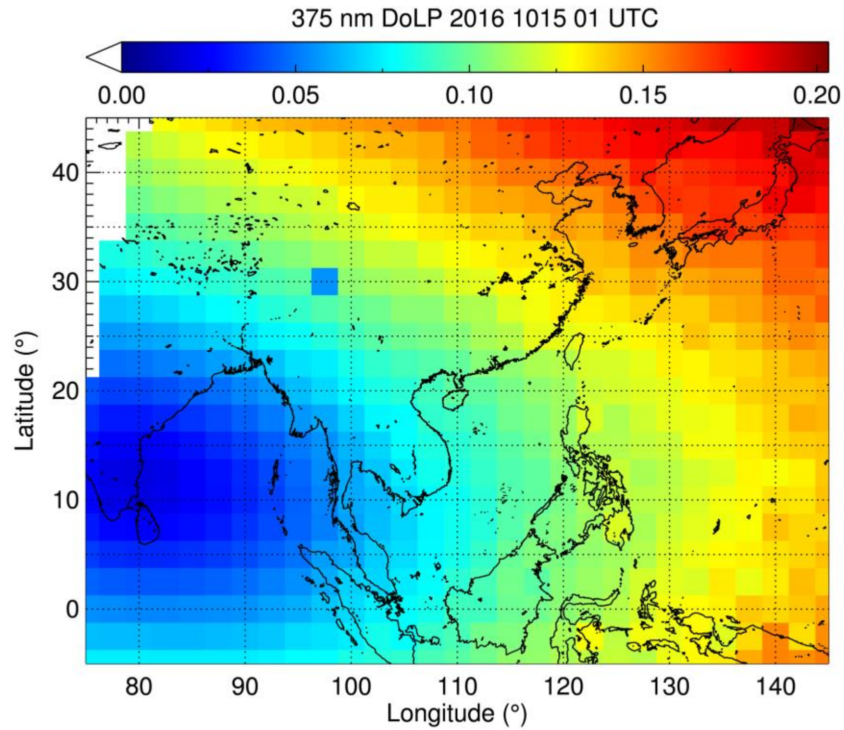
The three LPS curves are all below the GEMS requirement limit of 2%.

$$LPS = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \cong \frac{1}{2} f$$

Simulated results using the CodeV modeling. Polarization data is presented for three field points, the center of the slit, the end of the slit, and a field point hallway between them (5 nm resolution).

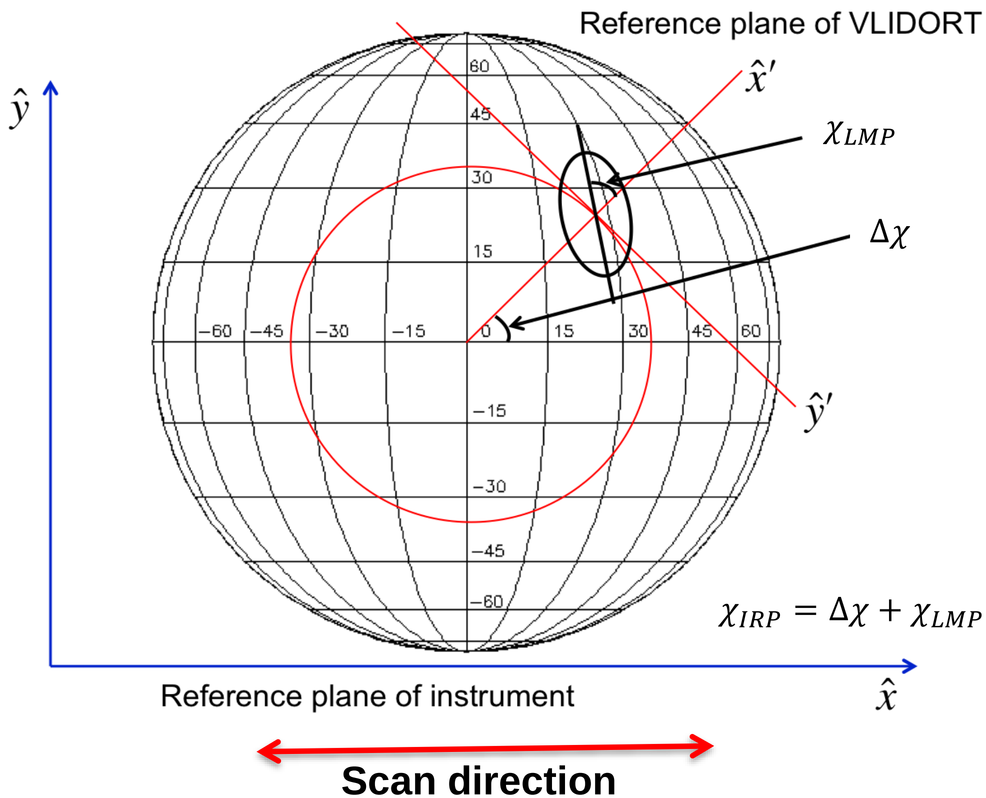
Simulations of the Stokes parameters

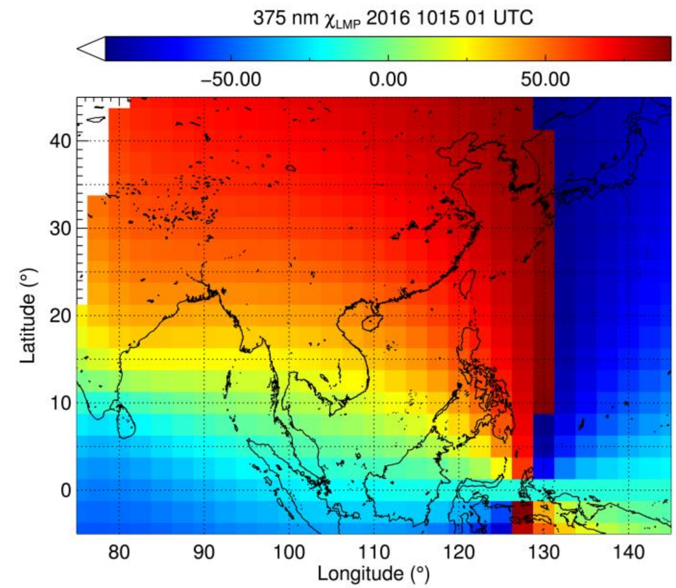


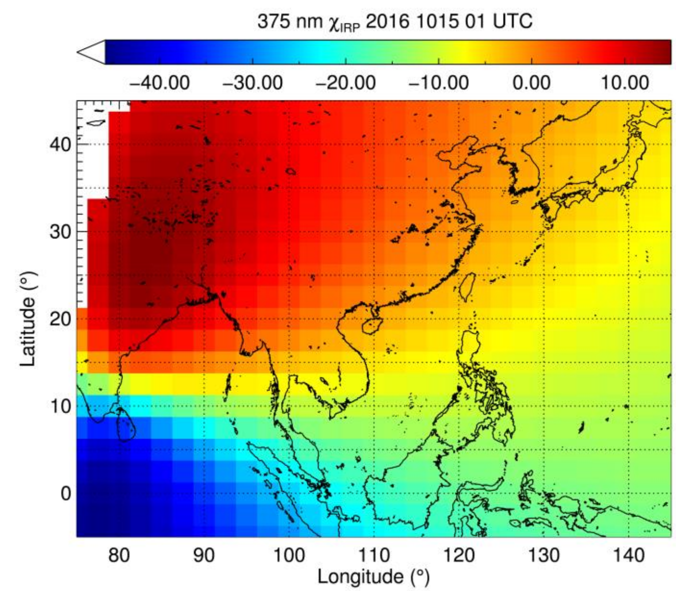


Simulations of Stokes vector using VLIDORT
TOMS ozone climatology
OMI Land LER climatology (+ Cox and Munk vector Ocean BRDF)
(MODIS BRDF for red channel)

Conversion of phase function w.r.t. local meridian plane to instrument scan plane







$$\Delta\chi \cong \tan^{-1}\left[\frac{\sin\theta}{\cos\theta\sin(\Delta\phi)}\right]$$

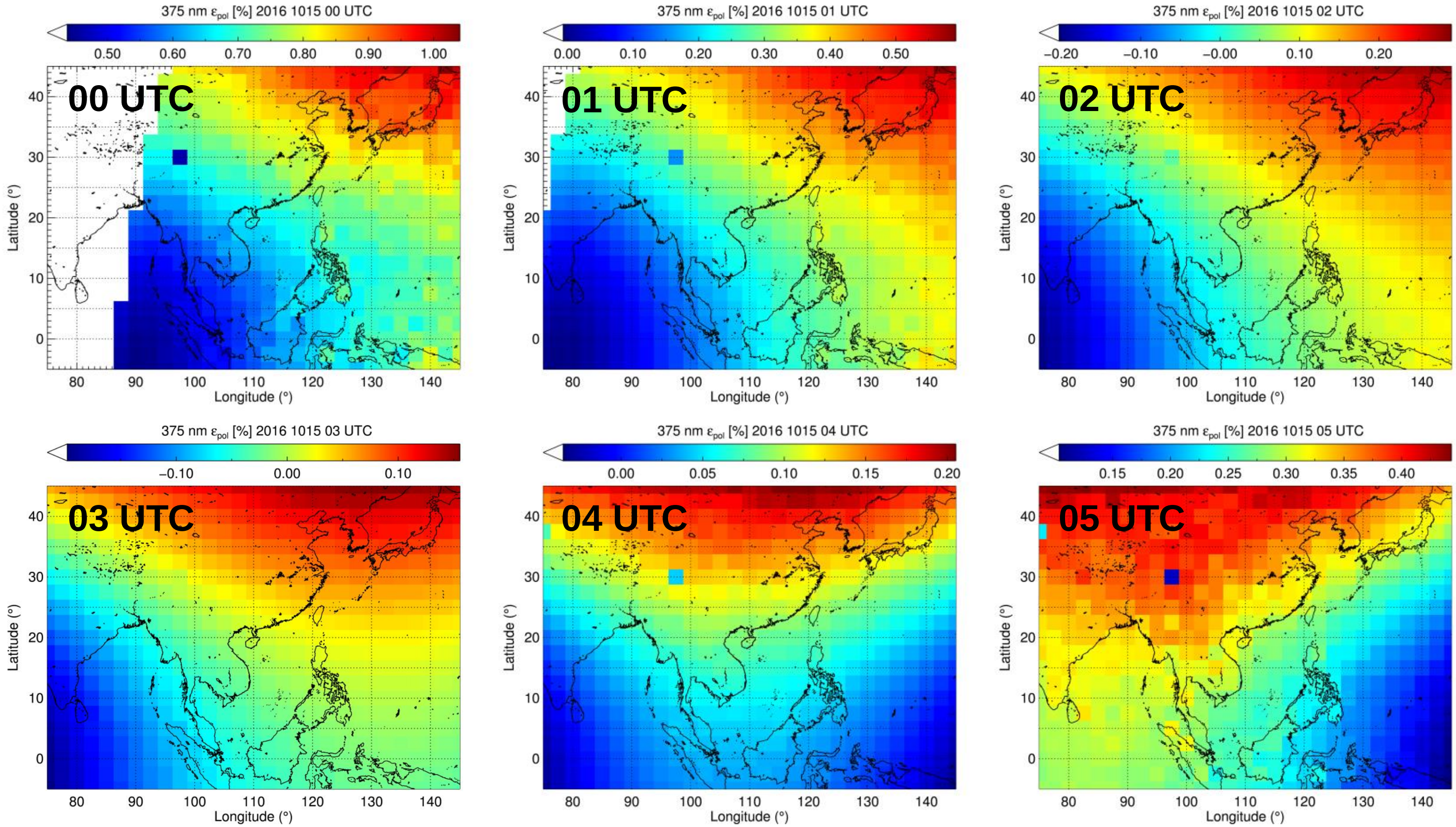
χ_{IRP}: Phase function w.r.t. Instrument reference plane

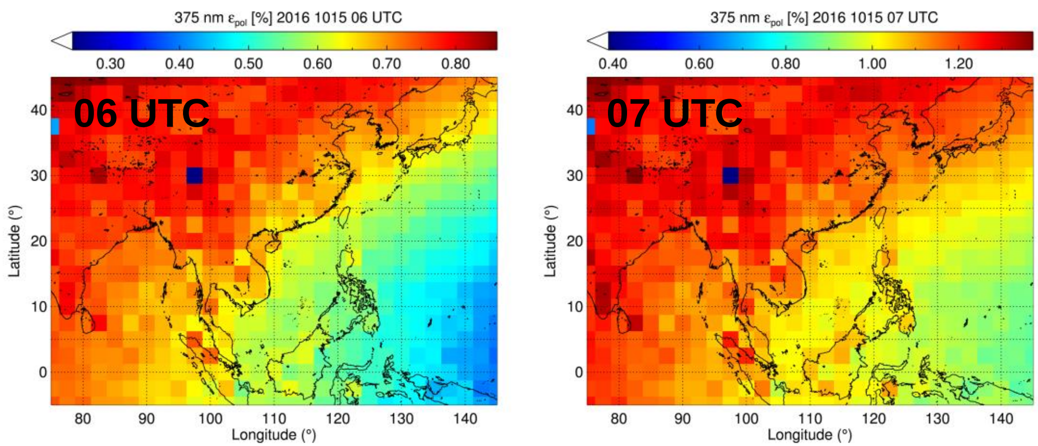
χ_{LMP}: Phase function w.r.t. Local Meridian Plane

$\Delta\chi$: Difference between χ_{IRP} and χ_{LMP}

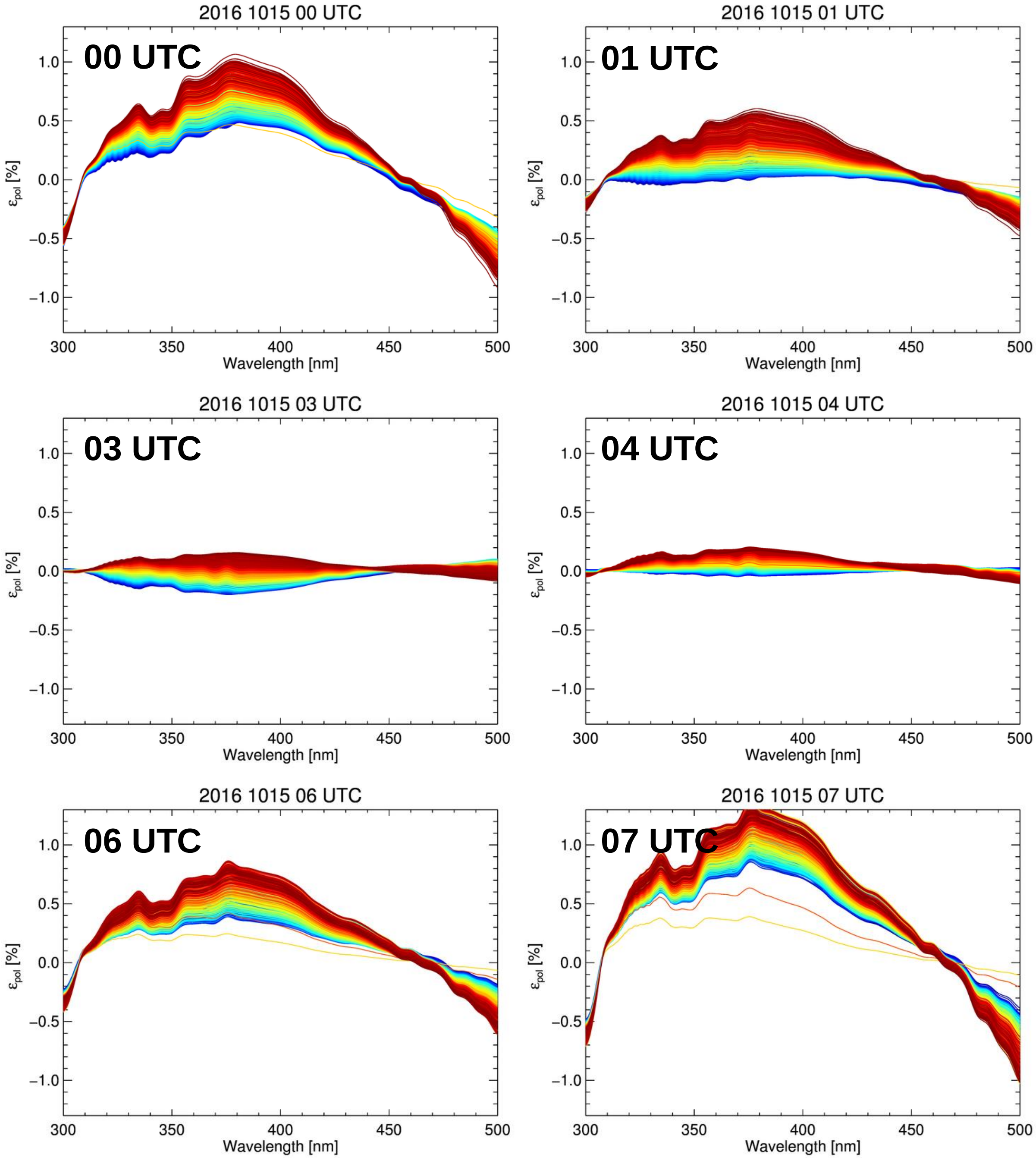
θ : Latitude of the ground location

$\Delta\phi$: Difference of Longitude between satellite and ground location



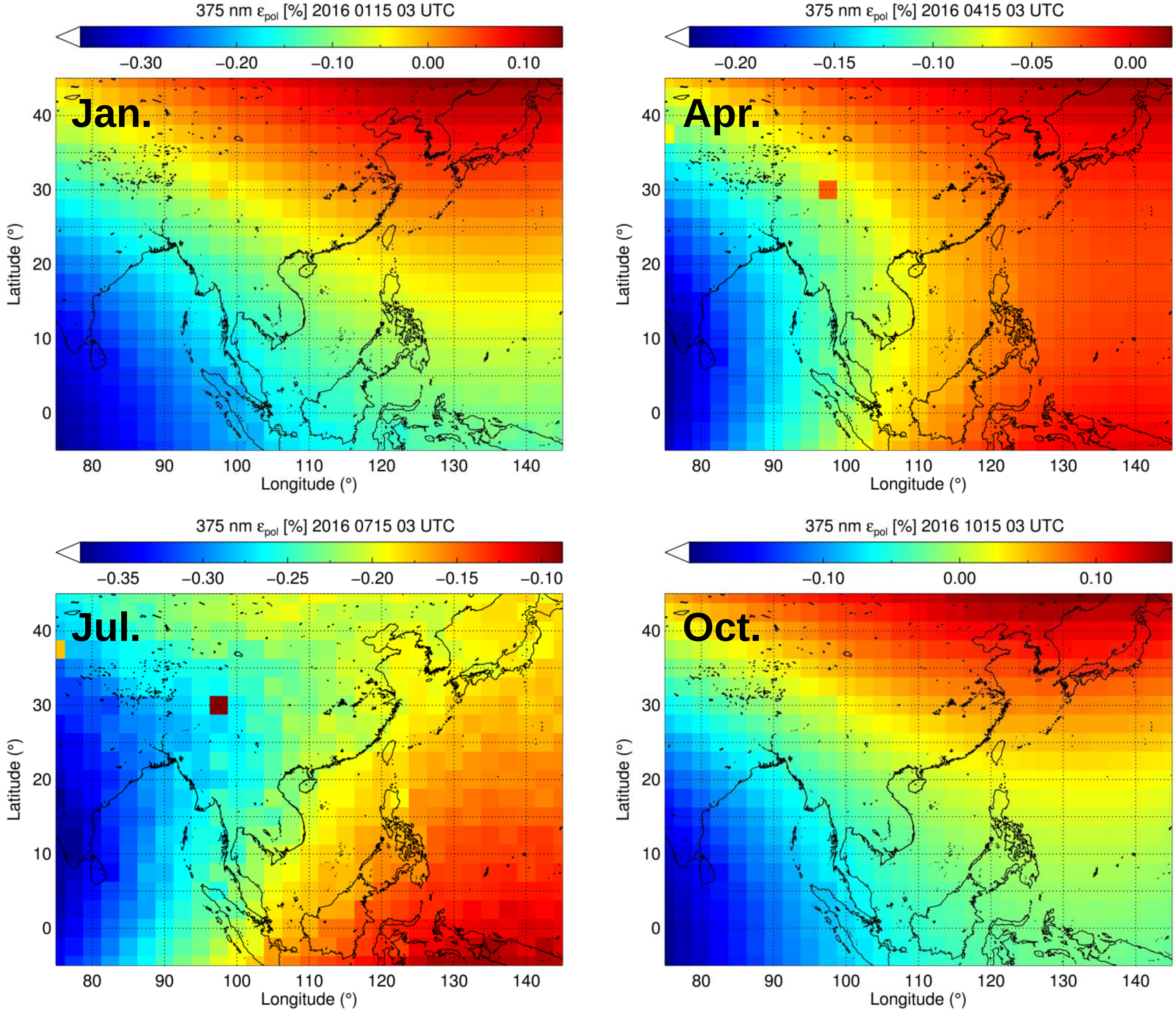


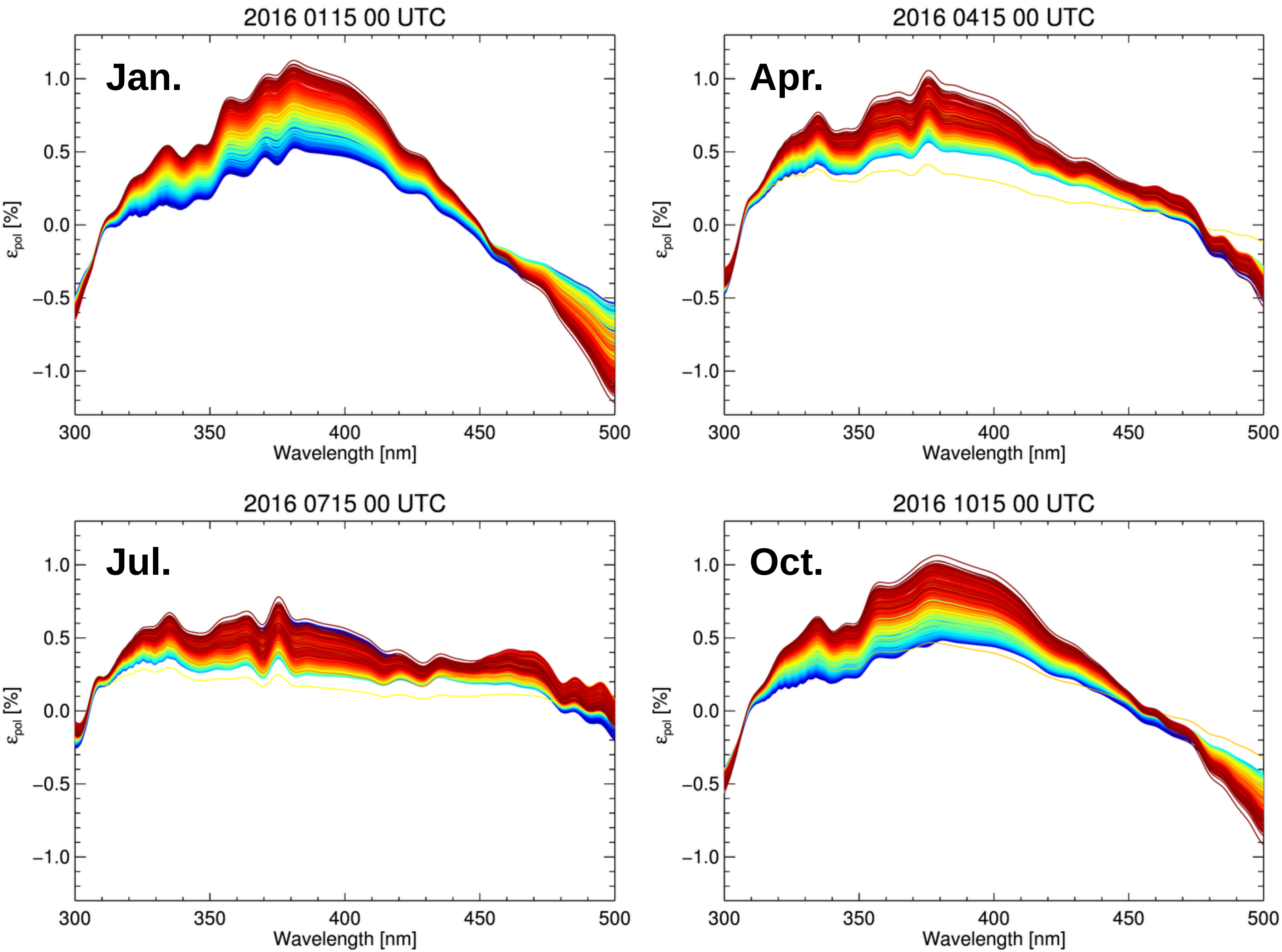
Diurnal variation of Radiance LPS bias



Diurnal variation of Radiance LPS bias

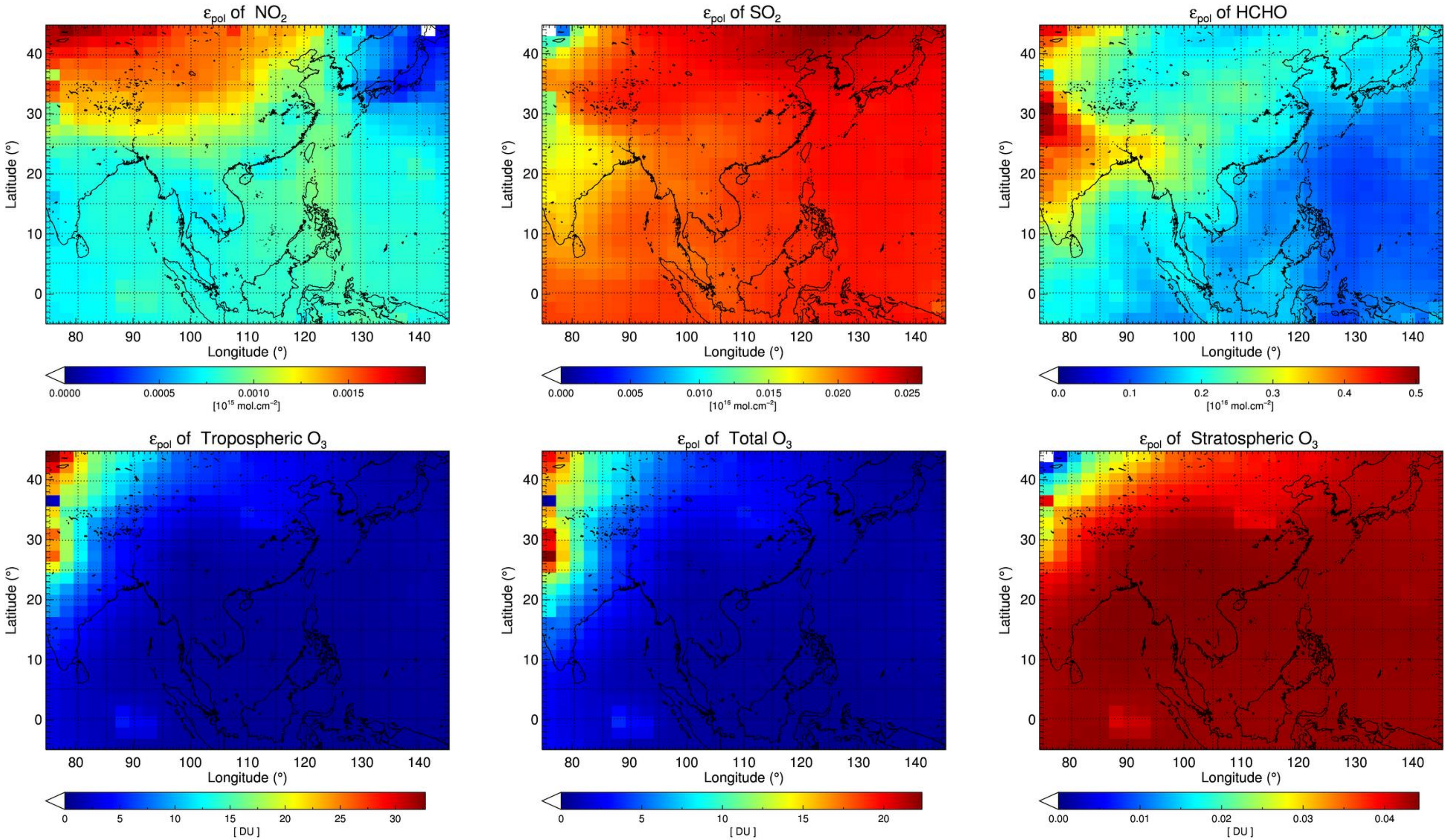
Seasonal variations of the Radiance LPS biases




2016 0115 00 UTC
Jan.
2016 0415 00 UTC
Apr.
2016 0715 00 UTC
Jul.
2016 1015 00 UTC
Oct.
ε_{pol} [%]
Wavelength [nm]
1.0
0.5
0.0
−0.5
−1.0
300
350
400
450
500

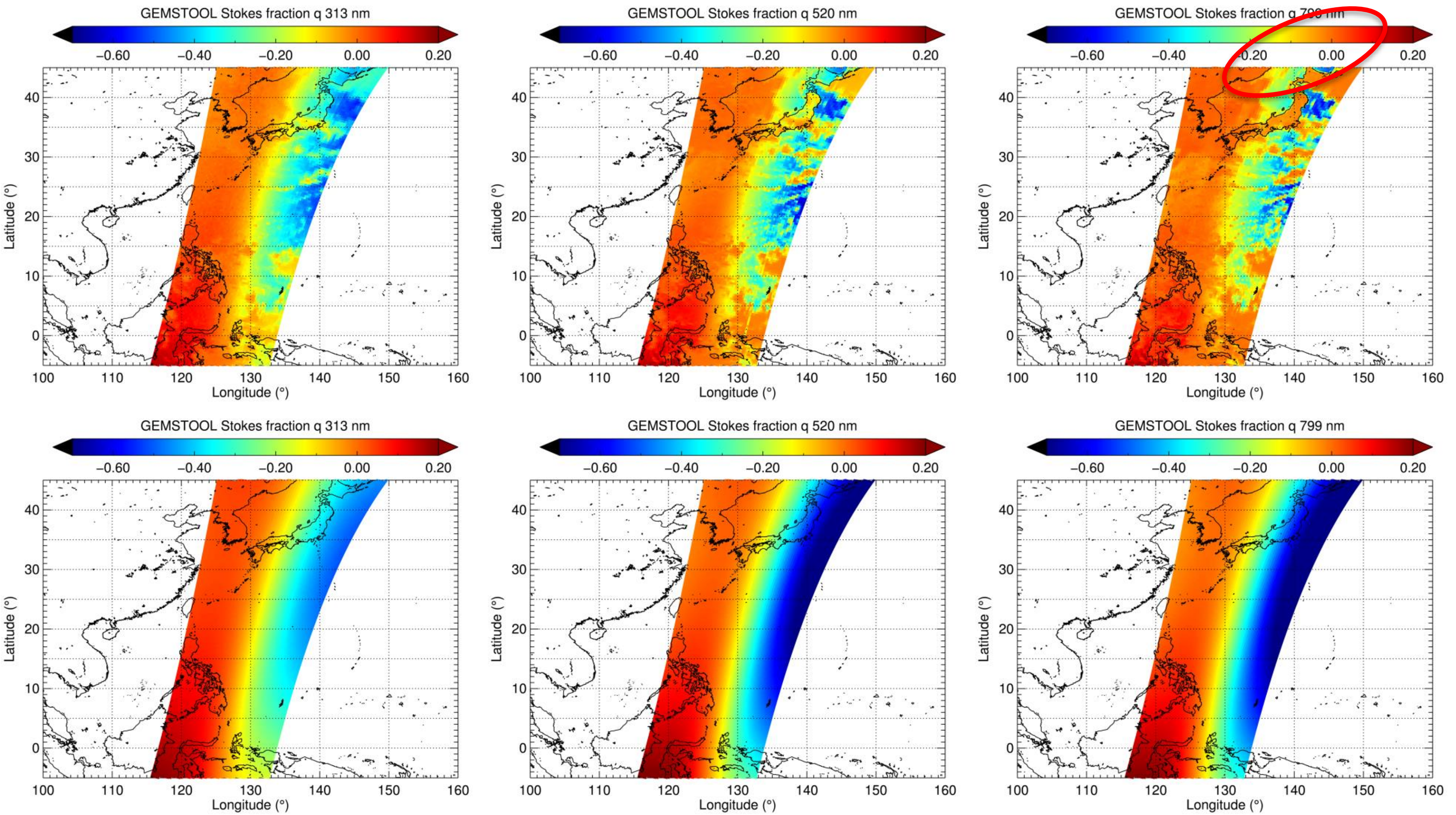
Effects of polarization sensitivity on trace gas retrievals

- **Annual mean bias error based on the optimal estimation method**
- **Important for tropospheric Ozone, HCHO**
- **Moderate for SO2**
- **Less important for NO2, stratospheric Ozone**



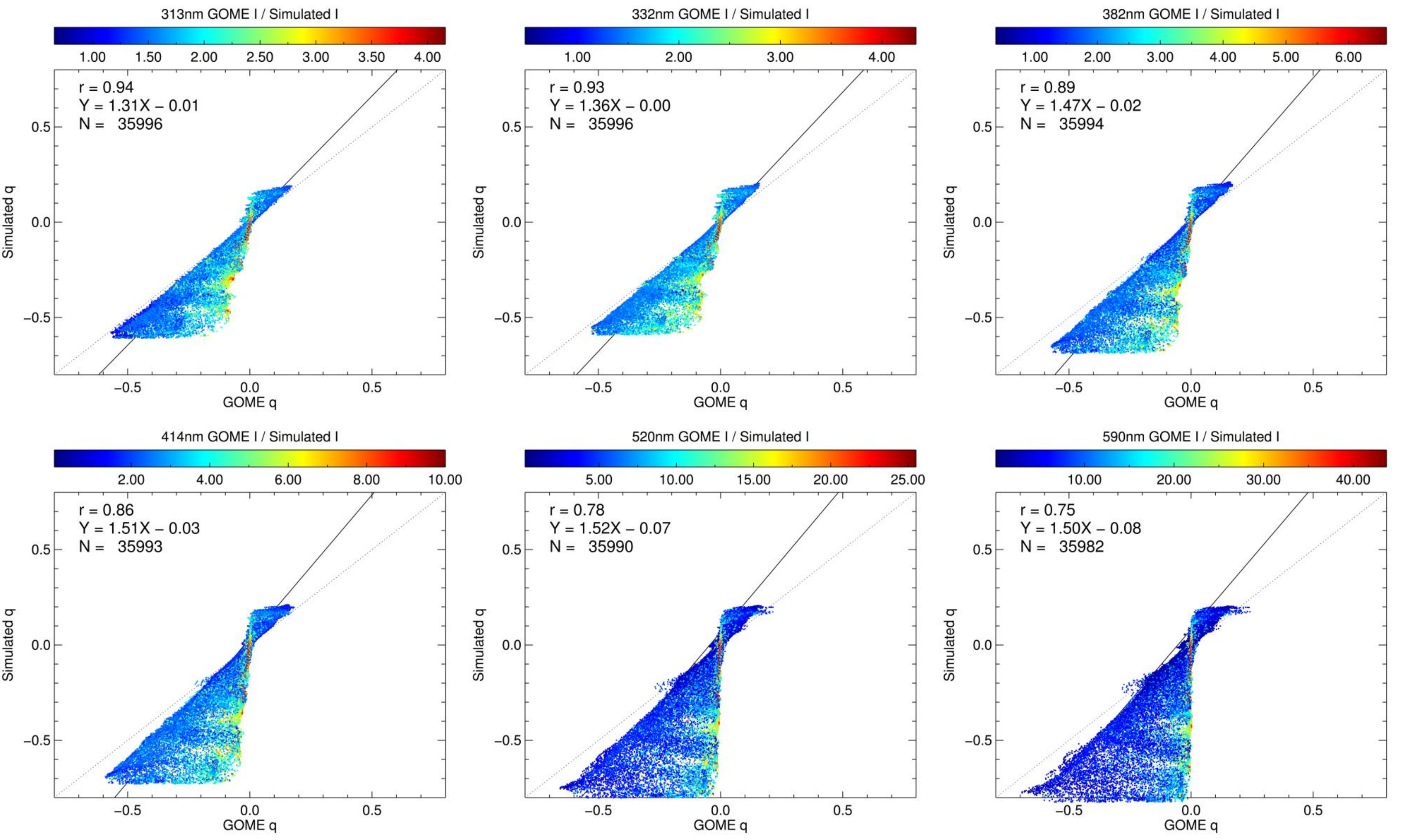
Comparison of simulated and measured Stokes parameter (1).

- **GOME-2 measurements in GEMS domain.**
- **Simulations without clouds and aerosols.**
- **Strong polarization by Rayleigh scattering.**
- **Clouds and aerosol effects becomes important as the wavelength becomes longer.**
- **Surface reflectance is important at long wavelength (799 nm)**



Comparison of simulated and measured Stokes parameter (2).

- **The Polarization is more predictable at short wavelength.**
- **Due to the surface, aerosol and cloud effects, larger discrepancies were found at longer wavelength**



Discussions and Future study

- **Reliable instrument characterization database is critical**

- **How to include the aerosol and cloud effect?**
  (aerosol and cloud information from other sensors?)

- **Look up table for the calculation is under development by Harvard SAO team.**

Thank you

Any comments / suggestions?