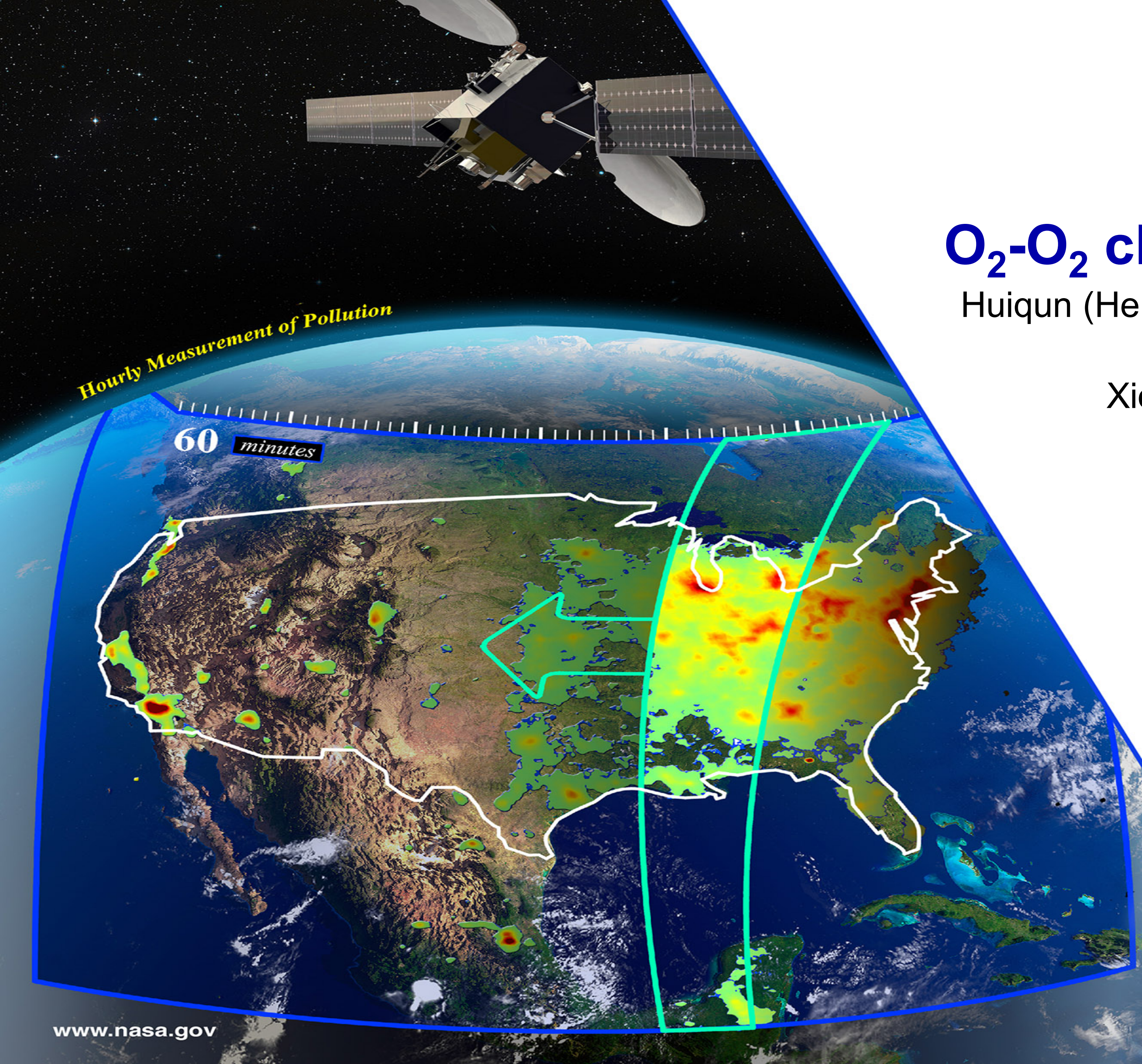


Tropospheric Emissions: Monitoring of Pollution

TEMPO

O_2-O_2 cloud algorithm for TEMPO

Huiqun (Helen) Wang, John Houck, Gonzalo Gonzalez Abad, Caroline Nowlan, Ewan O’Sullivan, Xiong Liu, Kelly Chance & The TEMPO Team

Smithsonian Astrophysical Observatory

Alexander Vasilkov, Eun-Su Yang

Science Systems and Applications Inc.

Joanna Joiner

NASA Goddard Space Flight Center

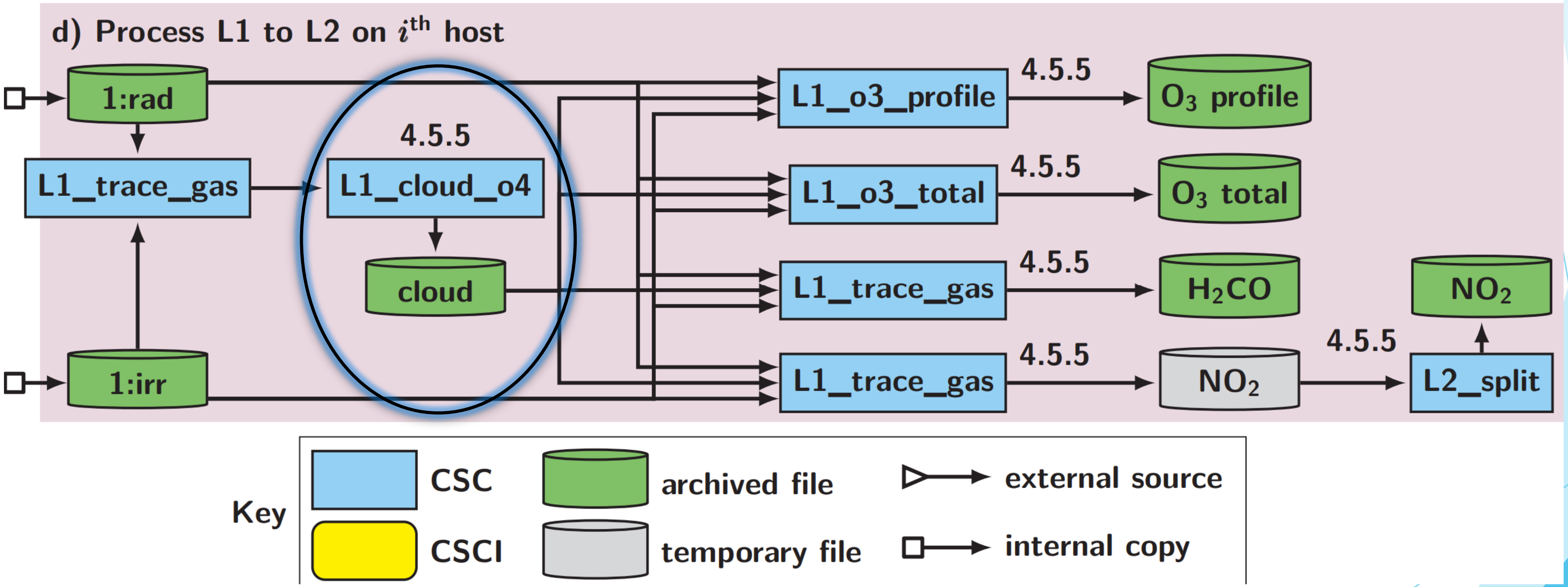
Robert Spurr

RT Solutions Inc.

TEMPO Science Team Meeting 2022

Smithsonian

Cloud_O4 is integrated into TEMPO SDPC pipeline



Adapting NASA OMI O_2-O_2 cloud algorithm to TEMPO

Vasilkov et al., 2018, Atmos. Meas. Tech., 11, 4093-4107, doi:10.5194/amt-11-4093-2018

A cloud algorithm based on the O_2-O_2 477 nm absorption band featuring an advanced spectral fitting method and the use of surface geometry-dependent Lambertian-equivalent reflectivity

Alexander Vasilkov[1], Eun-Su Yang[1], Sergey Marchenko[1], Wenhan Qin[1], Lok Lamsal[2], Joanna Joiner[3], Nickolay Krotkov[3], David Haffner[1], Pawan K. Bhartia[3], and Robert Spurr[4]

cloud albedo

$$I_m = I_g(R_g)(1-f) + I_c(R_c)f \quad (1)$$

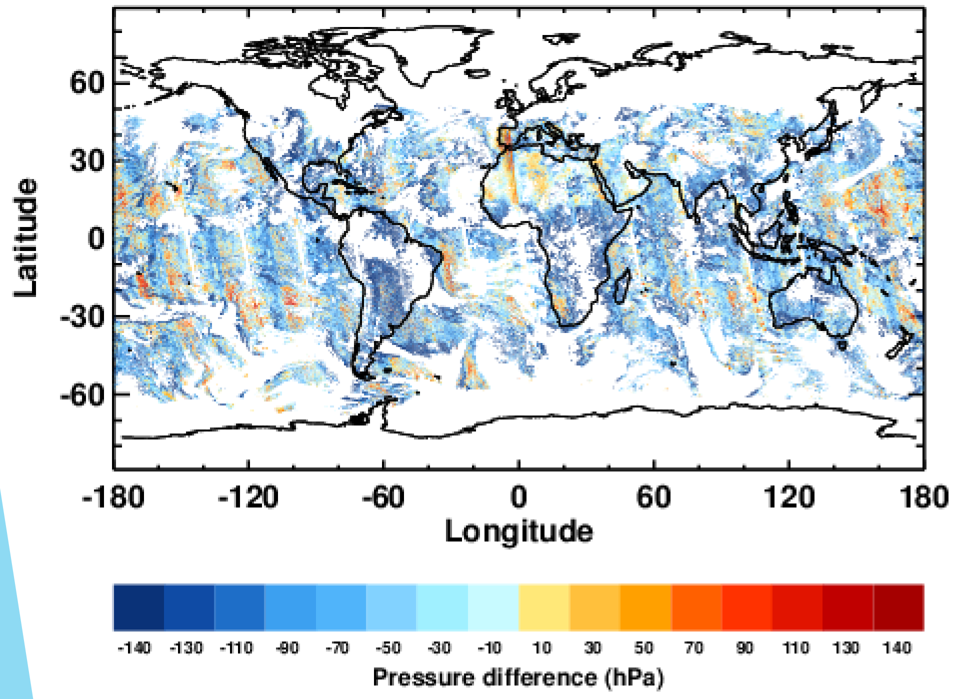
surface albedo — effective cloud fraction

surface pressure

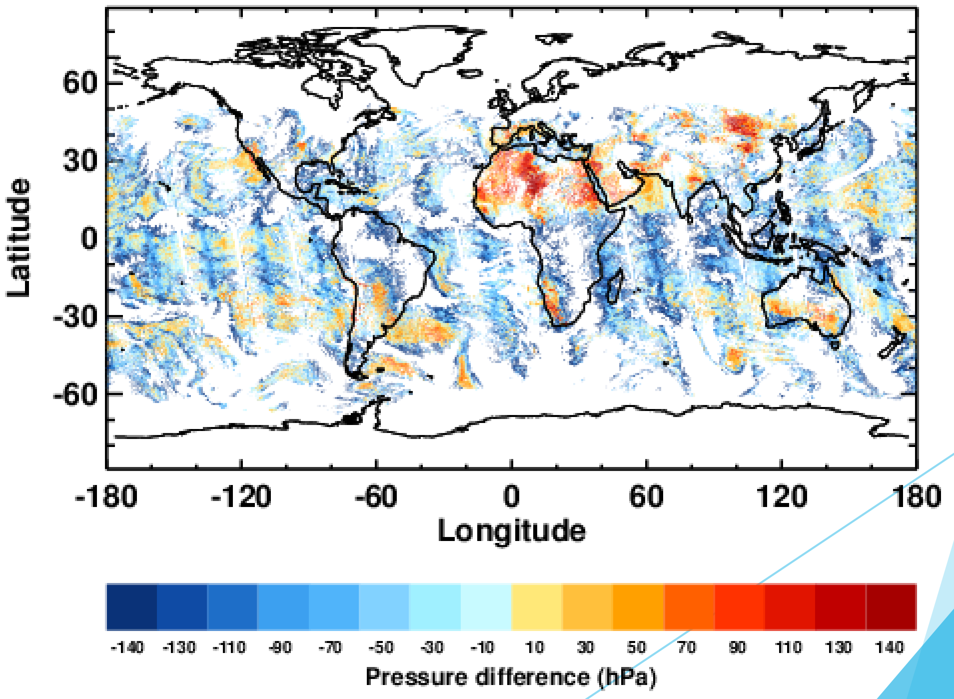
$$\mathrm{SCD} = \mathrm{AMF_g}(P_s, R_g)\mathrm{VCD}(P_s)(1-f_r) + \mathrm{AMF_c}(P_c, R_c)\mathrm{VCD}(P_c)f_r, \quad (4)$$

cloud optical centroid pressure

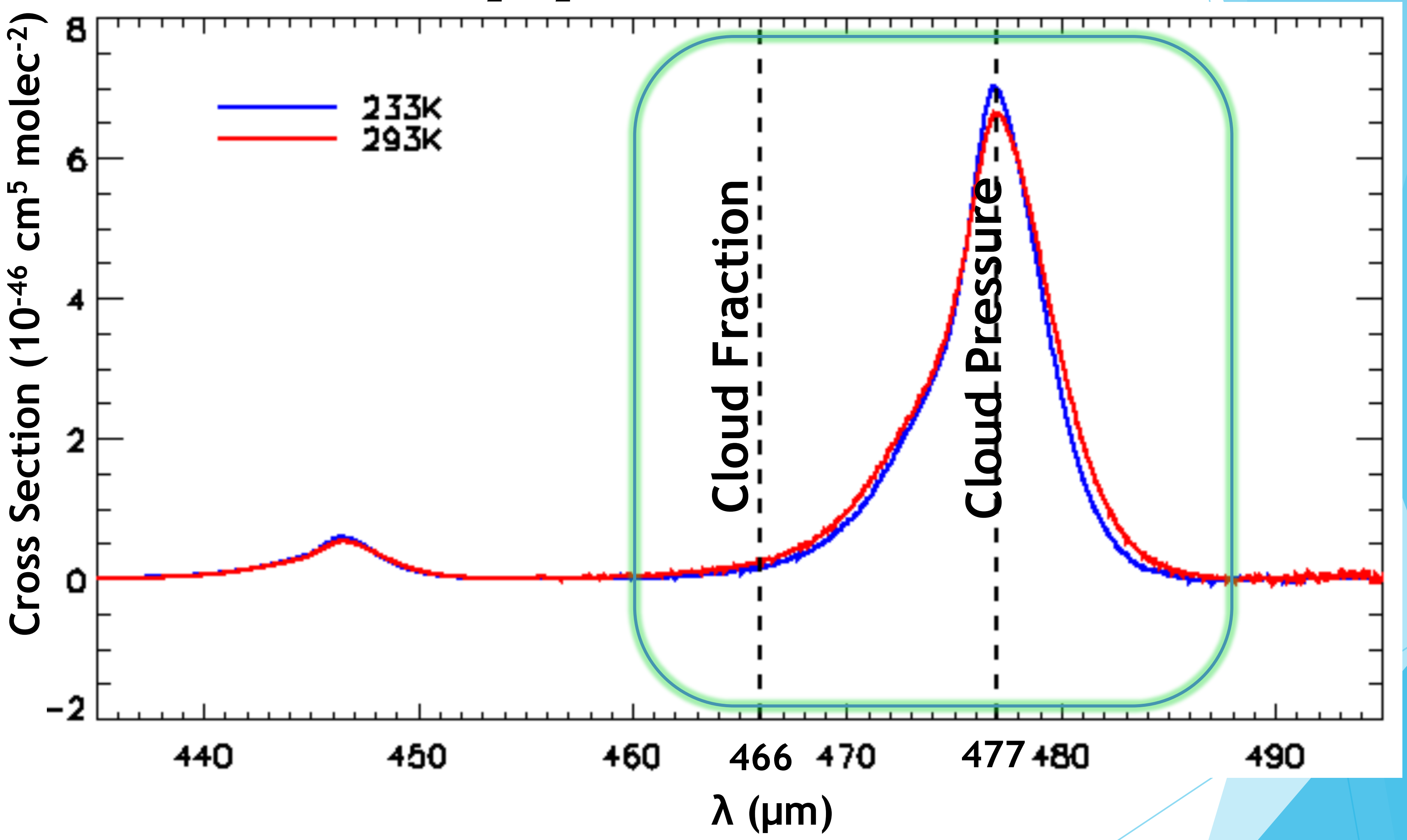
NASA



KNMI

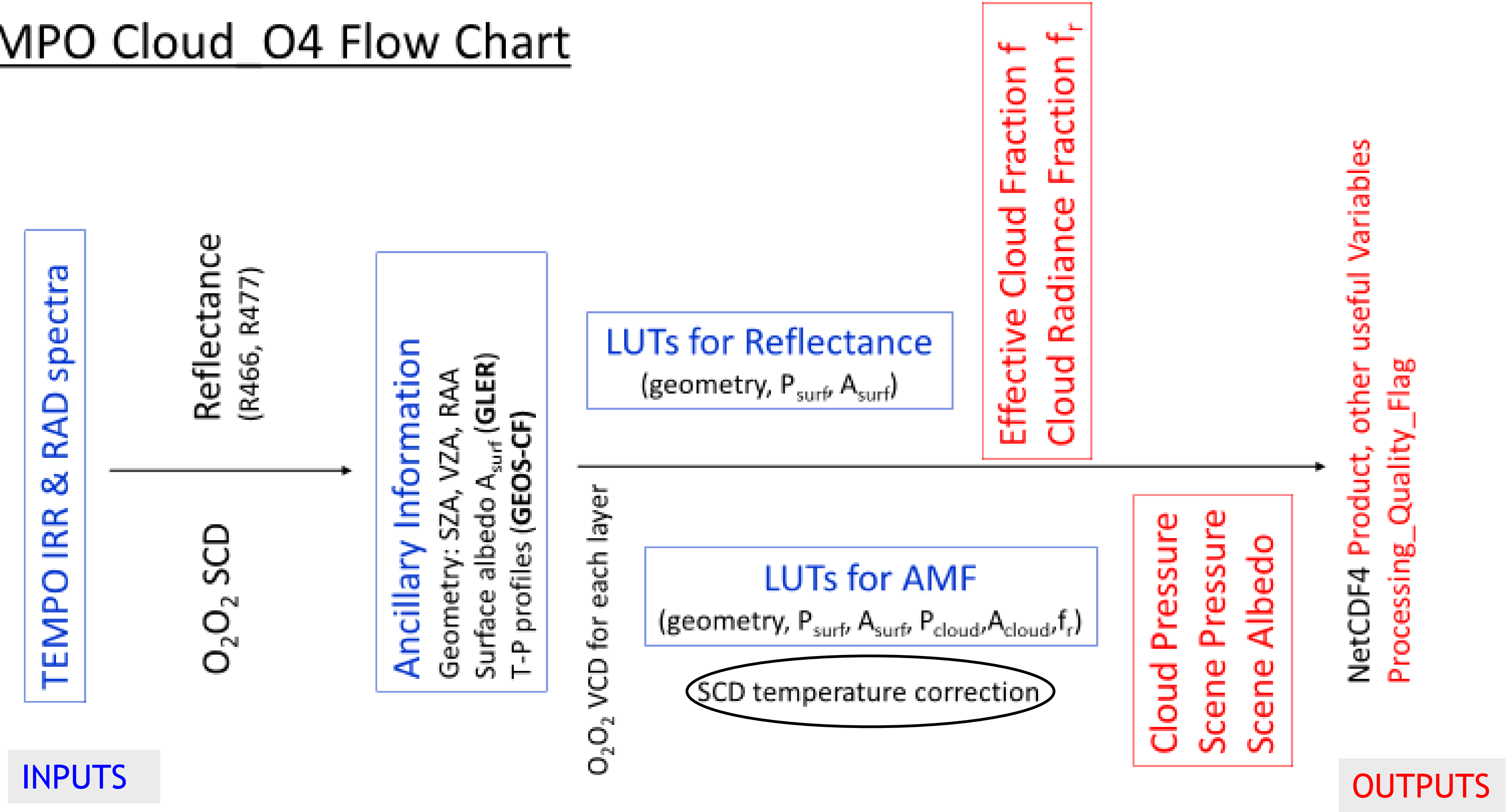


O_2-O_2 Reference Spectra



Effective Cloud Fraction (f) is calculated using the reflectance at 466 nm
Cloud Pressure is derived using the SCD retrieved from O_2-O_2 477 nm feature

TEMPO Cloud_O4 Flow Chart



Spectral Fitting O_2-O_2 SCD

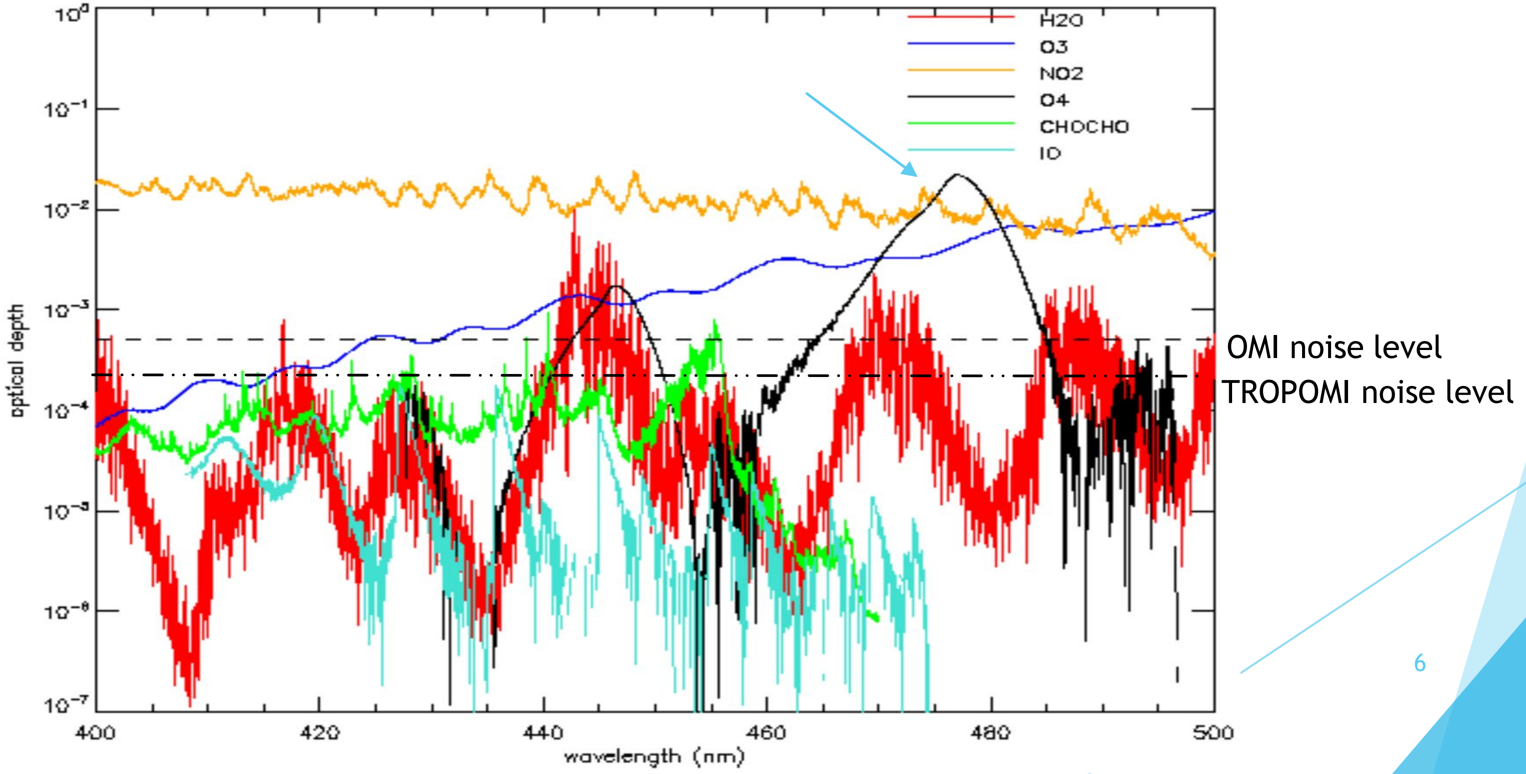
[Gonzalez Abad et al., 2015]

Irradiance — Beer-Lambert

$$I = \left[\left(a I_0 + \sum_i \alpha_i X_i\right) e^{-\sum_j \alpha_j X_j} + \sum_k \alpha_k X_k\right] \sum_n \alpha_n X + \sum_m \alpha_m X_m$$

Radiance — Add 1st — Add 2nd — Scaling — Baseline

Typical Beer-Lambert Contributions of Molecules



SAO's O2-O2 Slant Column Density Retrieval – TEMPO Operational algorithm

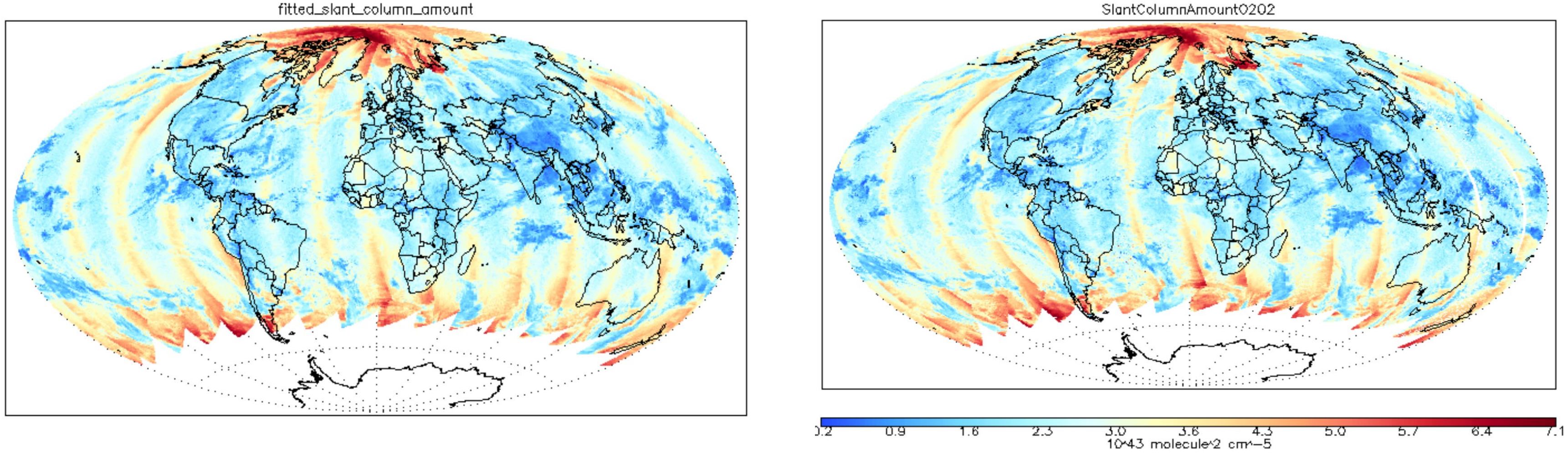
Table 1. Direct spectral fitting for O_2-O_2.

Fitting window	460.0-488.0 nm
Baseline polynomial	2nd order
Scaling polynomial	1st order
Solar reference spectrum	Chance and Kurucz (2010)
Raman Scattering	Derived using Chance and Spurr (1997)
Undersampling correction	Derived using Change et al. (2005)
Reference cross sections	O_3 Serdyuchenko et al., (2014) at 223K NO_2 Vandaele et al. (1998) 220K O_2-O_2 Finkenzeller and Volkamer (2022). H_2O HITRAN 2020 at 293K

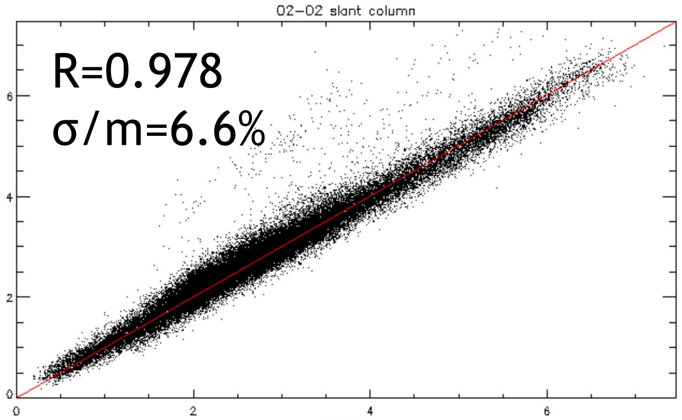
Comparison of OMI O_2-O_2 SCD

20050701 SAO

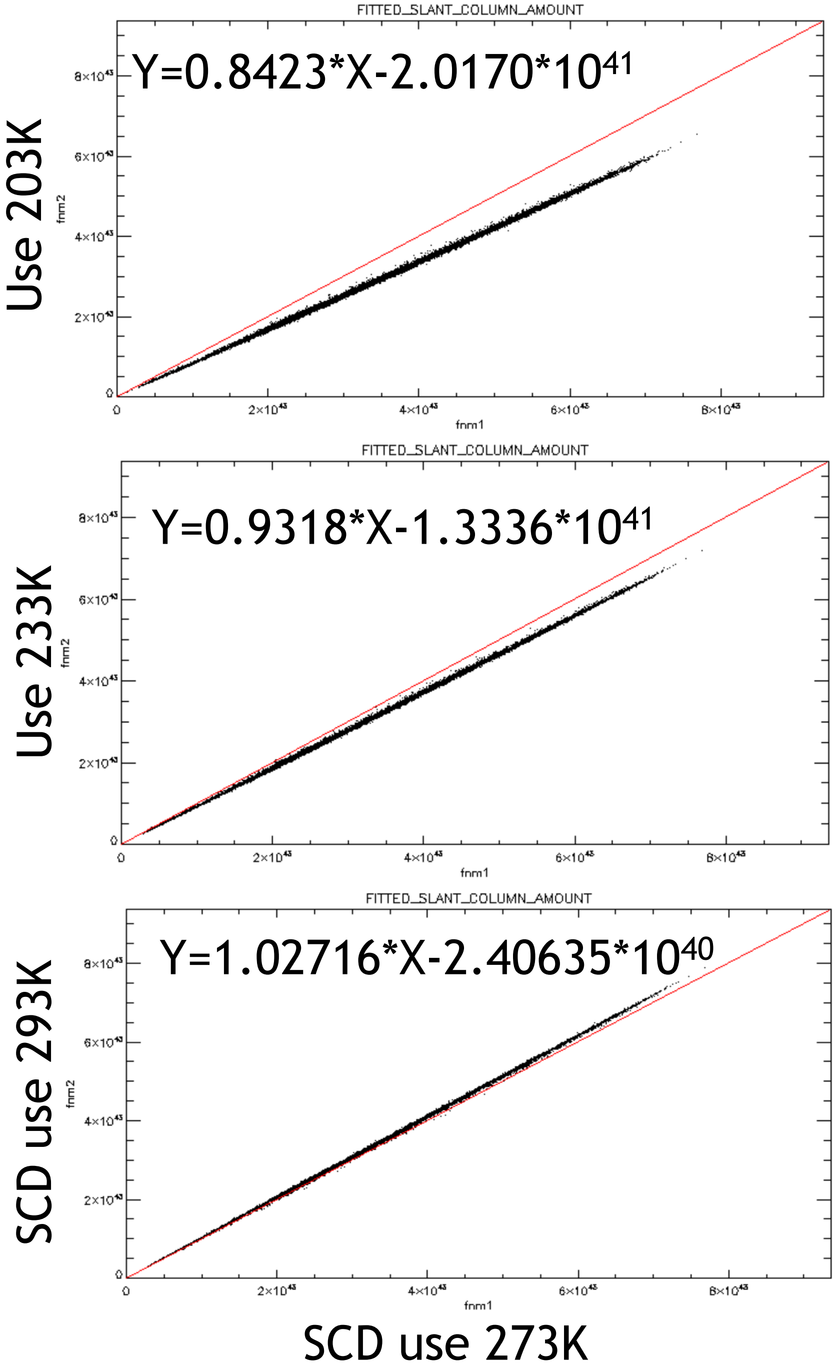
20050701 NASA OMCDO2N

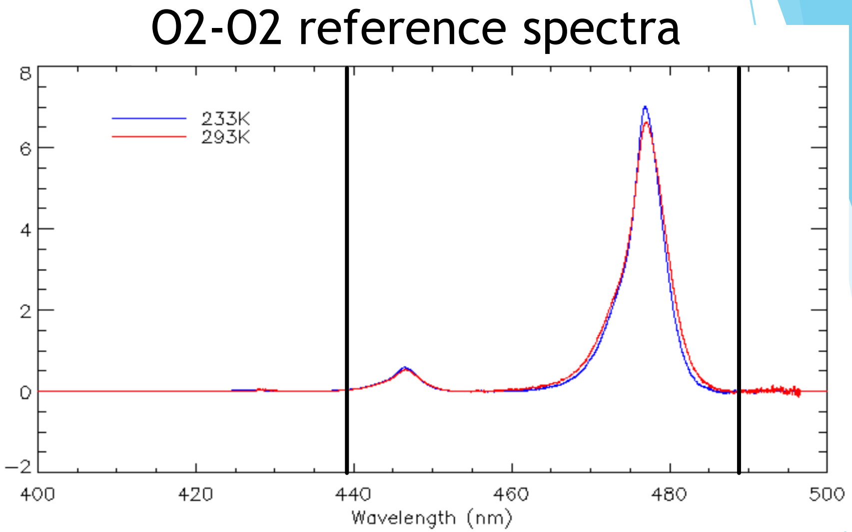


SCD Scatter Plot



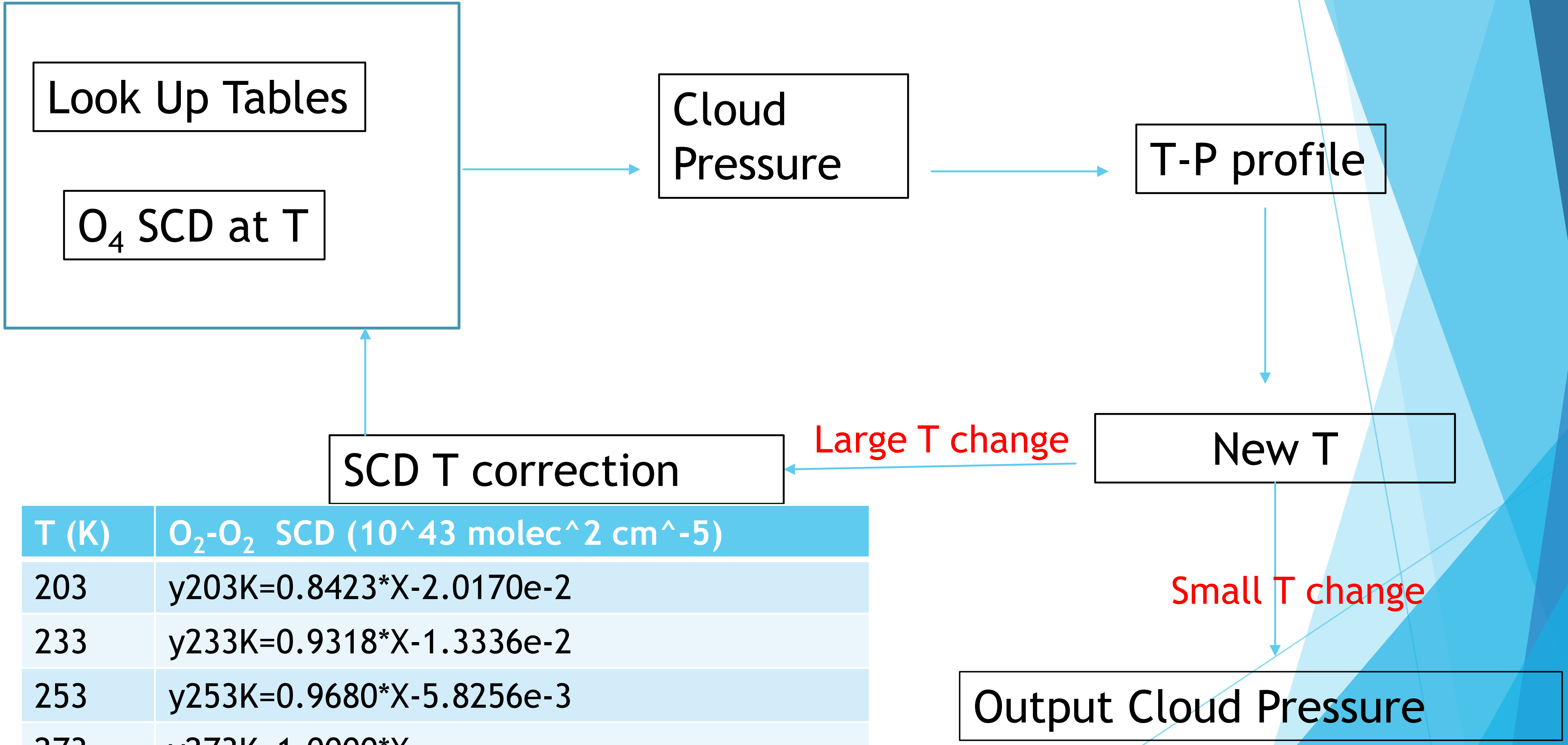
SCD dependence on O_2-O_2 temperature





T (K)	O_2-O_2 SCD (10^43 molec^2 cm^-5)
203	y203K=0.8423*X-2.0170e-2
233	y233K=0.9318*X-1.3336e-2
253	y253K=0.9680*X-5.8256e-3
273	y273K=1.0000*X
293	y293K=1.02716*X-2.4064e-3

O_2-O_2 SCD Temperature Correction



T (K)	O_2-O_2 SCD (10^43 molec^2 cm^-5)
203	y203K=0.8423*X-2.0170e-2
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253	y253K=0.9680*X-5.8256e-3
273	y273K=1.0000*X
293	y293K=1.02716*X-2.4064e-3

Look-Up Tables (LUTs) for TEMPO O_2-O_2 Cloud

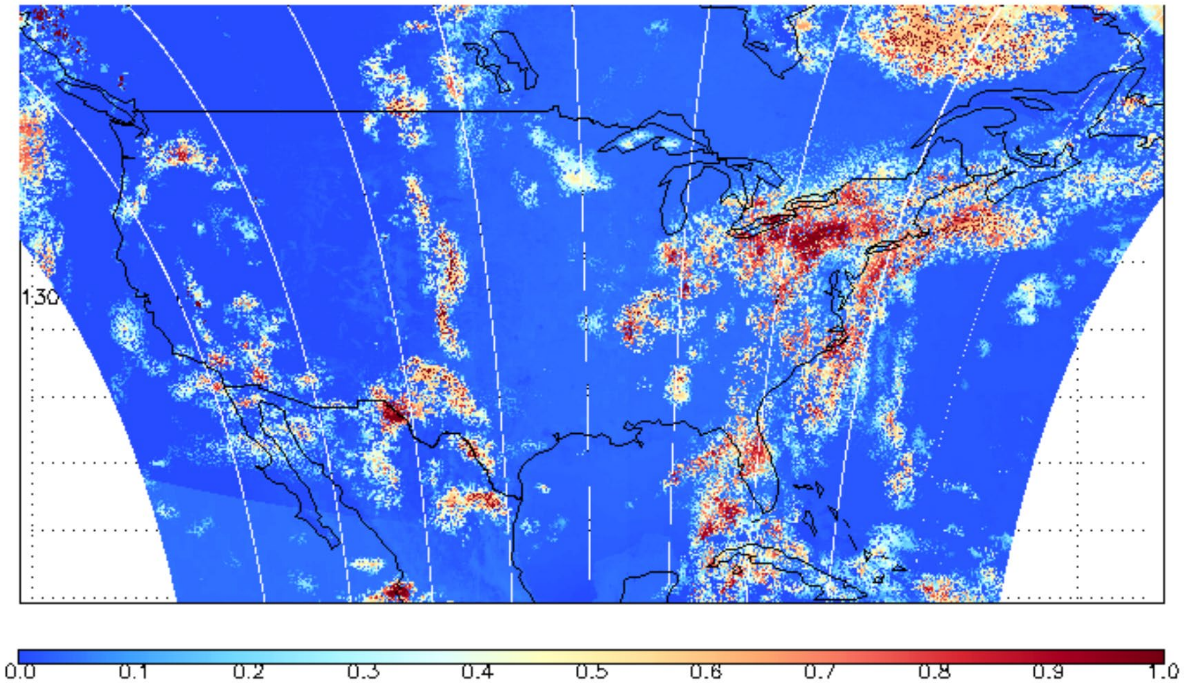
Variable	Nodes
Solar Zenith Angle	0,5,10,15,20,25,30,34,38,42,46,50,54,57,60,63,66,69,72,75,78,80,82,84,85,86,88.5,89
Viewing Zenith Angle	0,4,8,12,16,20,24,28,32,36,40,44,48,52,56,60,64,68,72,75,78,81,84,87,89
Relative Azimuth Angle	0,5,10,15,20,25,30,35,40,45,50,55,60,65,70,75,80,85,90,95,100,105,110,115,120,125,130,135,140,145,150,155,160,165,170,175,180
Surface Albedo	0.0,0.01,0.02,0.04,0.06,0.08,0.10,0.12,0.14,0.16,0.18,0.20,0.30,0.40,0.50,0.60,0.70,0.80,0.90,1.00
Surface/Cloud Pressure (hPa)	1100,1050,1013,899,795,701,617,541,472,357,308,265,227,194,166,142,121,104,89,76,65,55

(1) TOA Reflectance at 466nm
(2) TOA Reflectance at 440nm
(3) Scattering Weight at 477nm for clear sky
(4) Scattering Weight at 477nm for overcast sky
(5) Scattering Weight at 477nm for Scene Albedo and Scene Pressure

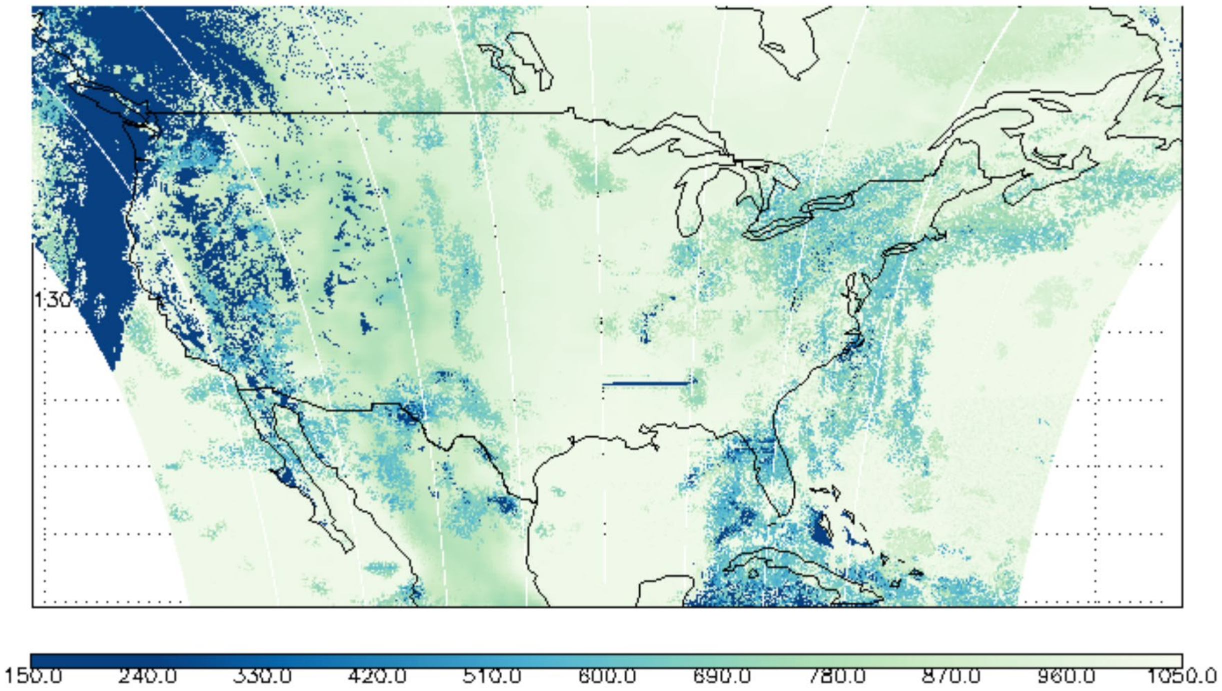
Calculated using **VLIDORT V2p8p3**
48 layers based on US standard air
Assuming 325 DU of Total Ozone

Results using Synthetic TEMPO spectra

effective cloud fraction



cloud pressure (Pa)



The cloud O4 algorithm is working in the TEMPO SDPC pipeline