TEMPO NO_2 Algorithm Development: Lessons Learned from OMI and Aircraft Retrievals

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with contributions from

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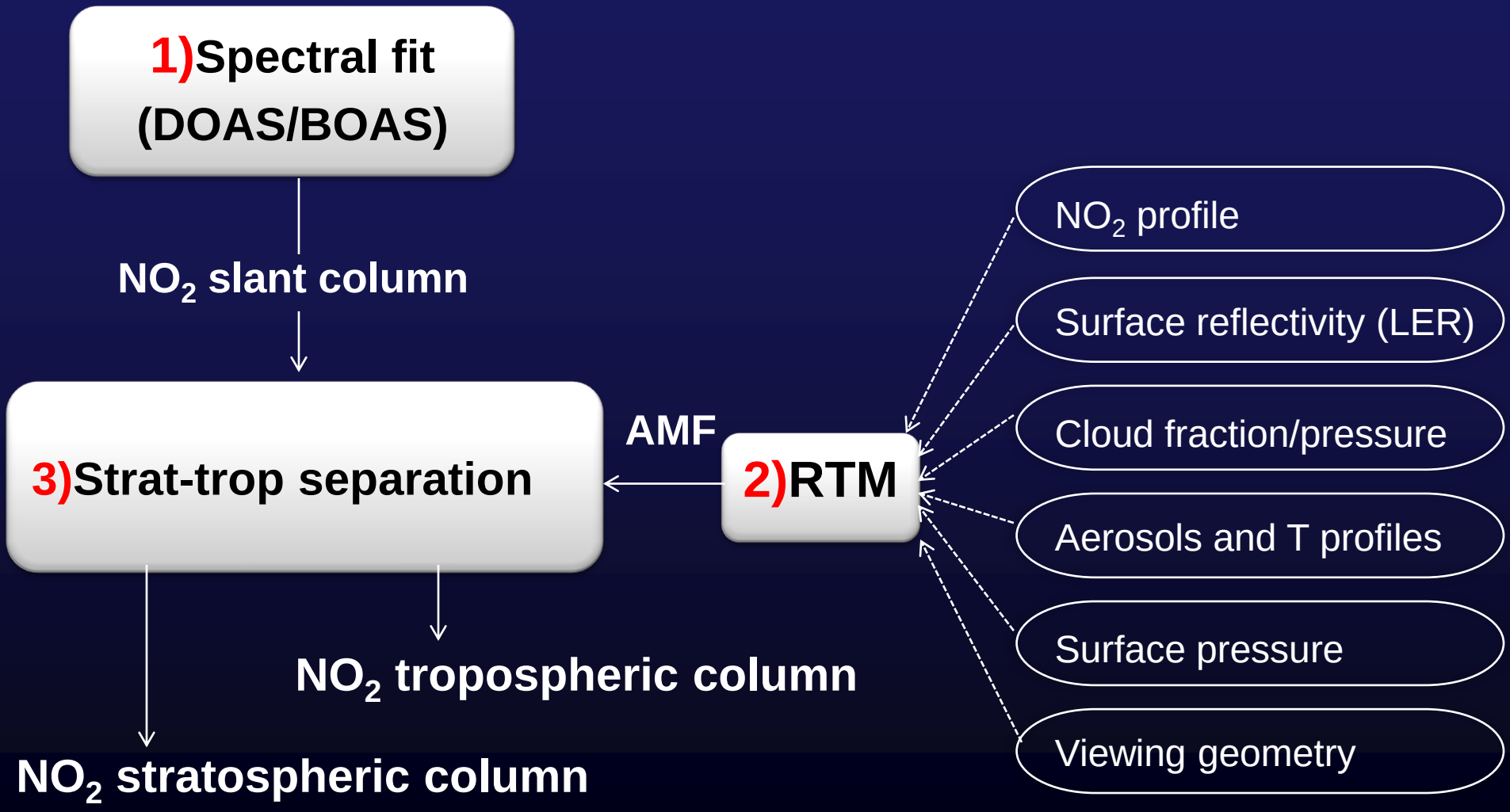
Two Relevant Papers

Vasilkov et al., Accounting for the effects of surface BRDF on satellite cloud and trace-gas retrievals: A new approach based on geometry-dependent Lambertian-equivalent reflectivity **(LER)** applied to OMI algorithms, *Atmos. Meas. Tech. Disc.*, 2016.

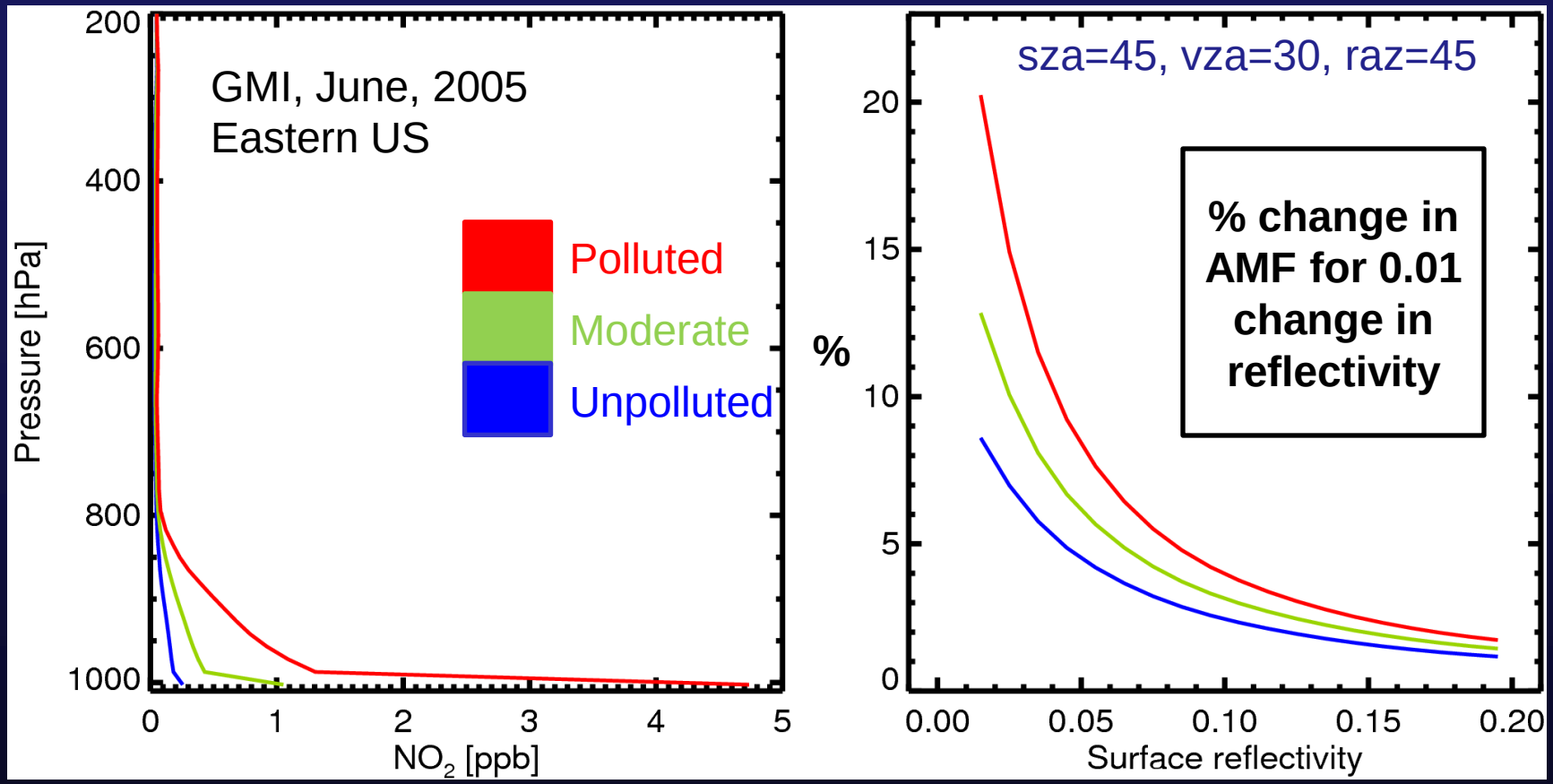
Lamsal et al., High resolution NO_2 observations from the Airborne Compact Atmospheric Mapper: Retrieval and Validation, J. Geophys. Res. (to be submitted).

Retrieval Scheme for Stratospheric and Tropospheric NO_2



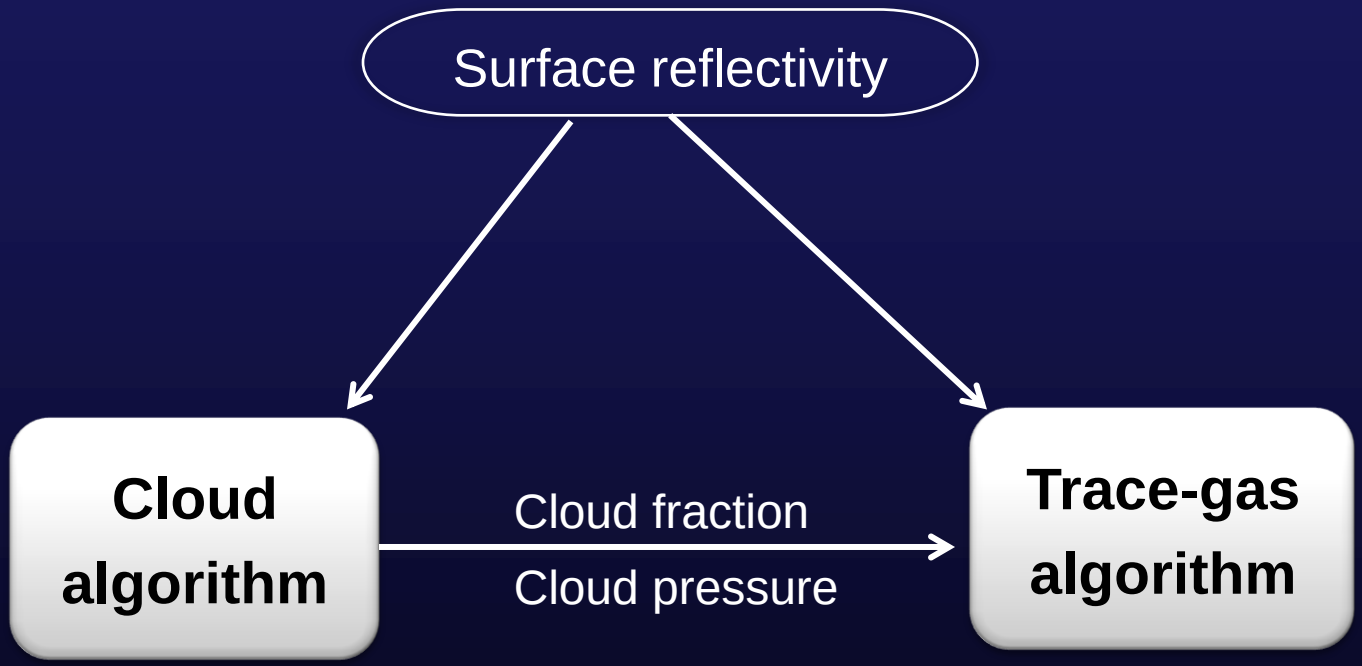
Strat-trop separation → Next talk by Jeffrey Geddes

Sensitivity of AMF to Surface Reflectivity



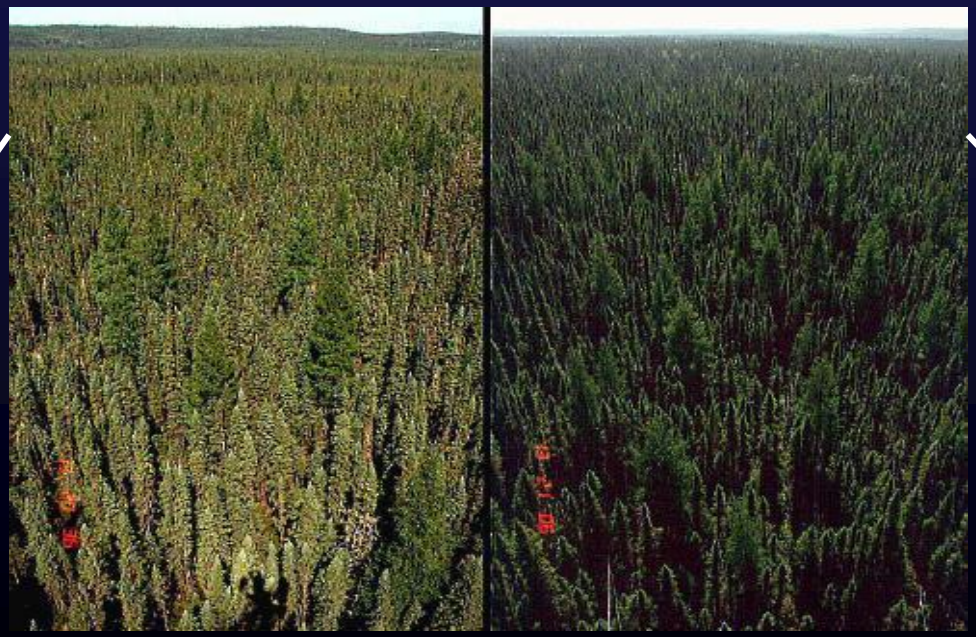
- 0.01 change in surface reflectivity can change retrieval by 2-20%. Changes are larger for polluted areas and low reflective surfaces.

Surface Reflectivity Affects Trace-gas Retrievals directly (via AMF) and indirectly (via cloud correction)



Surface Reflectivity and Trace-gas Retrievals: Issues

- **Operational cloud and trace-gas algorithms use climatological surface LER data base (OMI or TOMS-based) for surface reflectivity**
  - Coarse resolution (0.5°×0.5°)
  - Cloud and aerosol contaminations
  - Independent of geometry, but reflection of incoming light depends on observational geometry described by Bidirectional Reflectance Distribution Function (BRDF)



Backscattering: Sun behind observer

Forward scattering: Sun opposite of observer

Surface Reflectivity and NO_2 Retrievals: Issues

- **Some of the issues with climatological data can be addressed using MODIS data, but MODIS products include different reflectivity types:**

  WSA as LER (valid only when diffuse radiation >> direct radiation)

  BSA as LER (incorrect single and multiple scattering contribution)

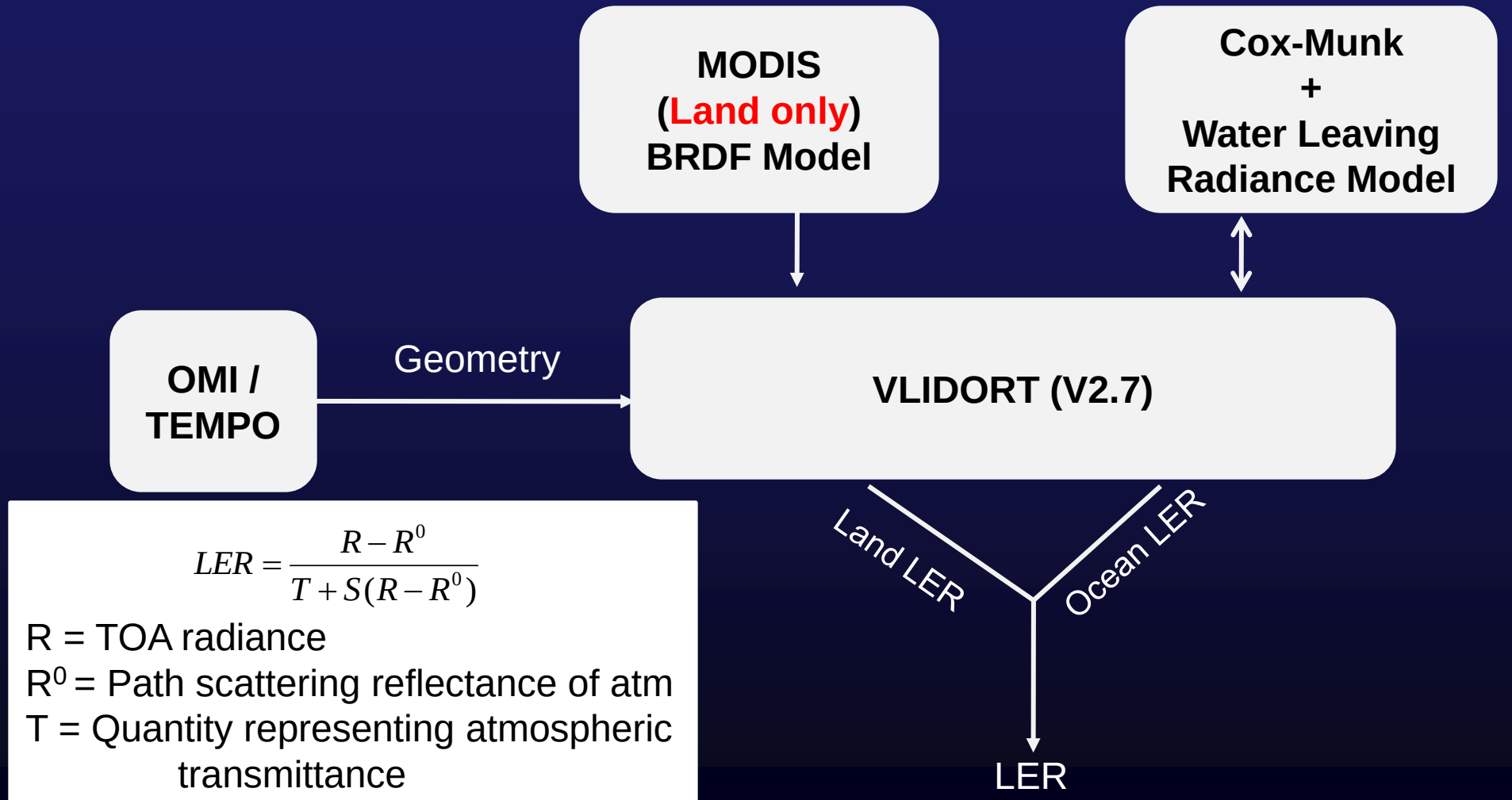
  BRF as LER (incorrect multiple scattering contribution)

Studies/product	Reflectivity type (MODIS)	Modification in cloud retrieval?
Russell et al., 2011 (BEHR)	BSA as LER	No
Zhou et al, 2012	BSA, WSA, BRF as LER also, Complete BRDF model	No
Lin et al., 2015 (POMINO, Dalhousie AMF)	Complete BRDF model	Yes

- All previous studies are **limited over land**
- Calculating AMF with BRDF model is **computationally expensive**

Development of Geometry-dependent LER

Vasilkov et al, AMTD, 2016



$$LER = \frac{R - R^0}{T + S(R - R^0)}$$

R = TOA radiance

R^0 = Path scattering reflectance of atm

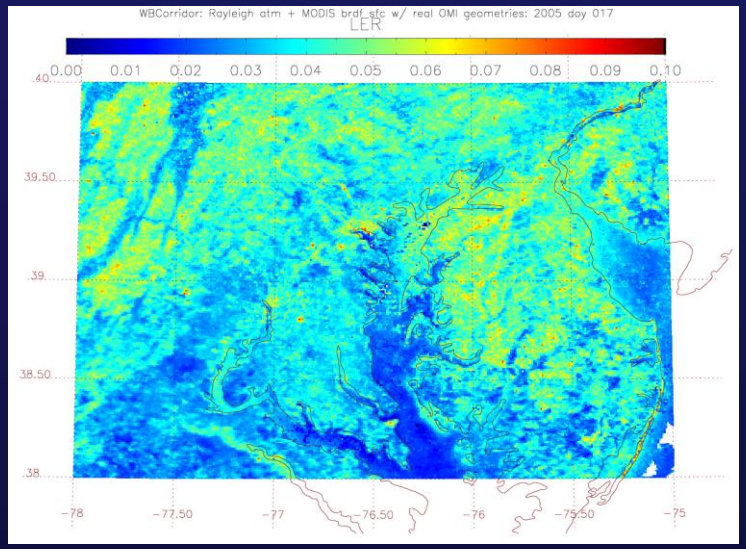
T = Quantity representing atmospheric transmittance

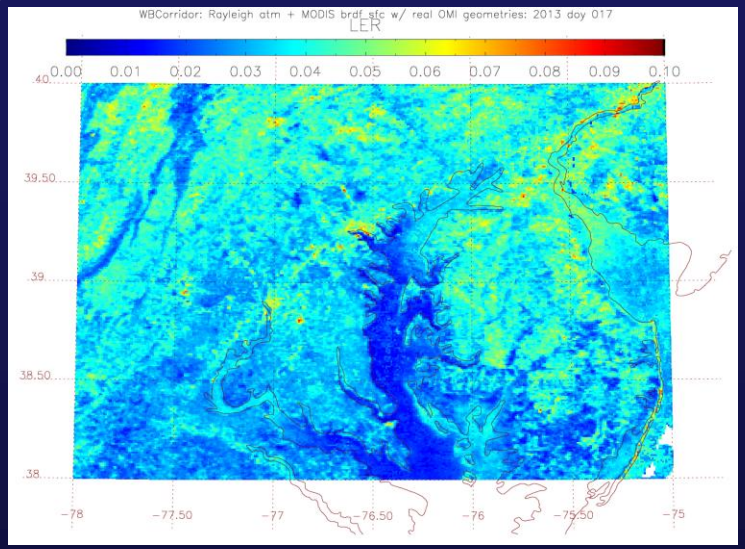
S = Spherical albedo of atmosphere

- Applicable to both land and water surface
- Algorithms remain unchanged

Same Area, Different Days, Different Years, Different LERs

High-resolution MODIS BRDF-derived LER (466 nm) at OMI geometry (DC-Baltimore)





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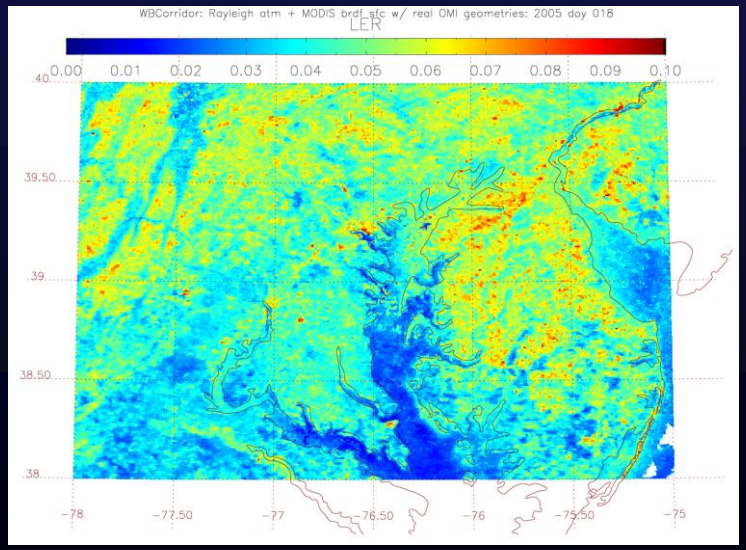
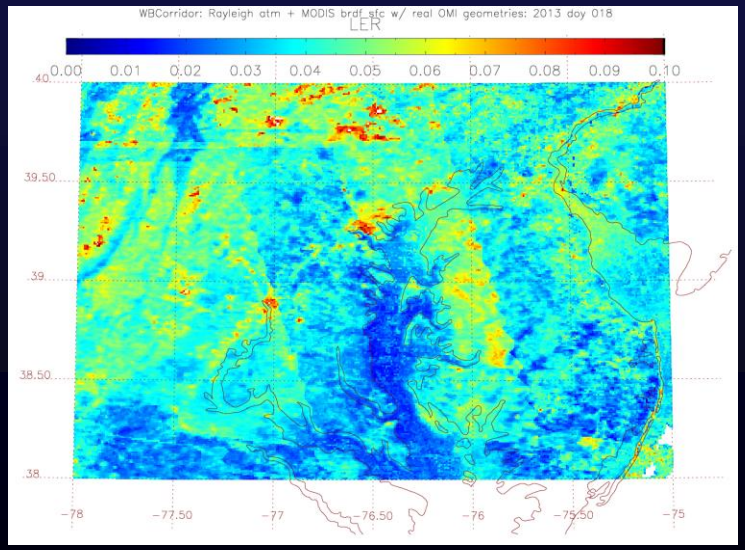




DOY=18

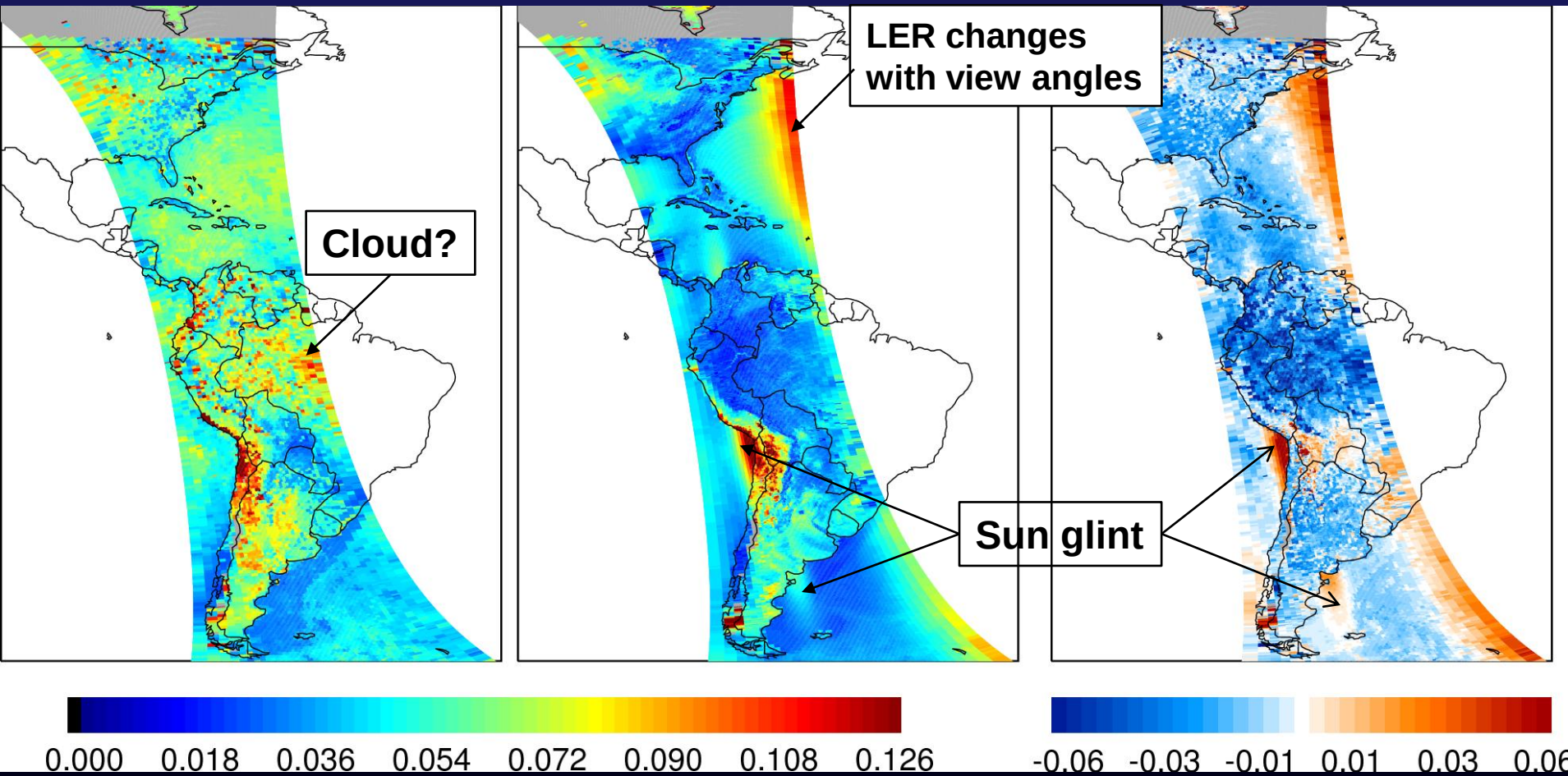
2005 **2013**

Surface Reflectivity (LER) Comparison

OMI LER (440 nm)
(Kleipool et al, 2008)

MODIS-derived LER (440 nm)
(This work)

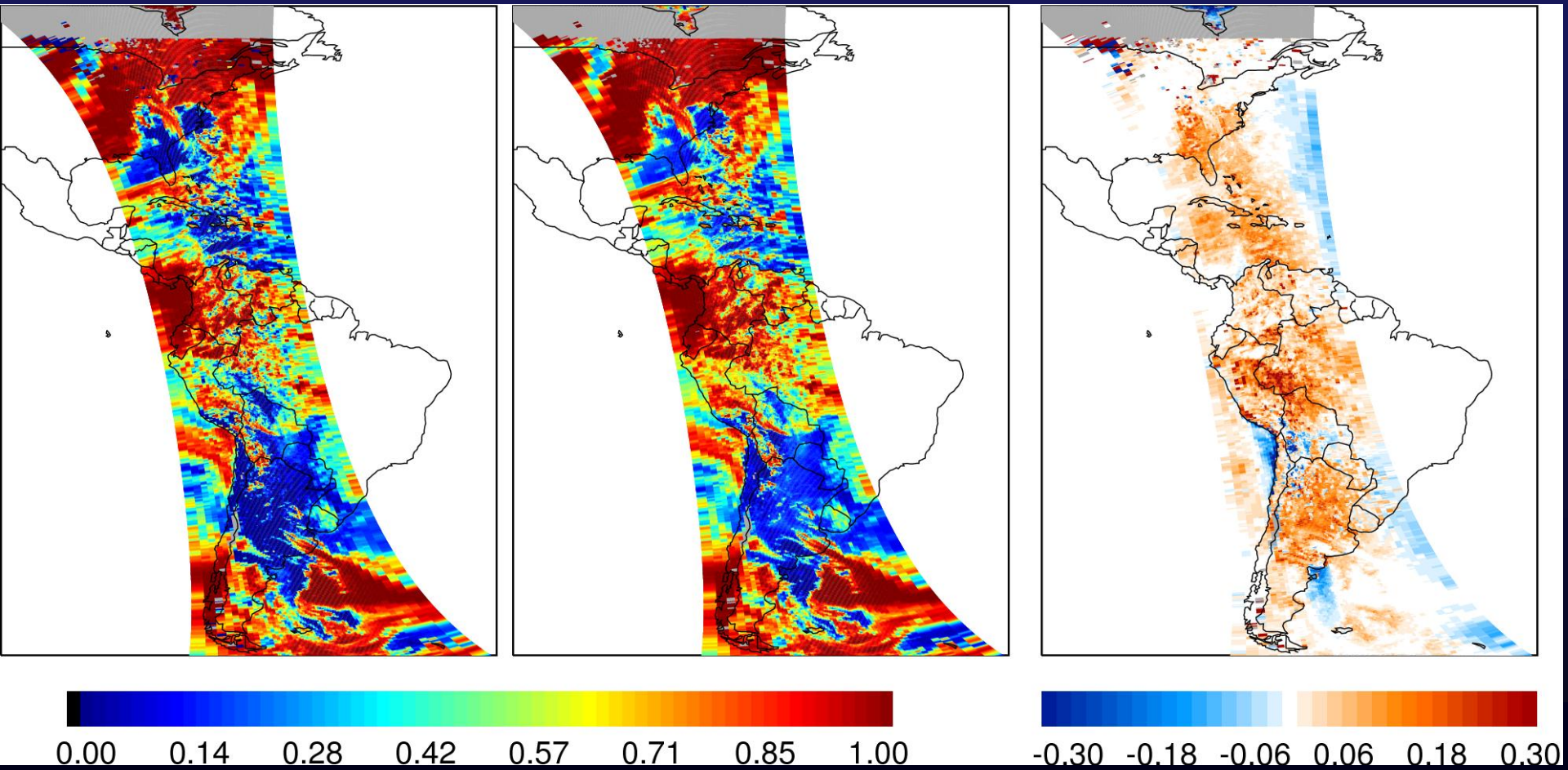
Difference
(MODIS – OMI LER)



OMI orbit 012414 (November 14, 2006)

Cloud Radiance Fraction (CRF) Comparison

CRF with OMI LER | **CRF with MODIS-derived LER** | **Difference (MODIS-based – OMI-based)**



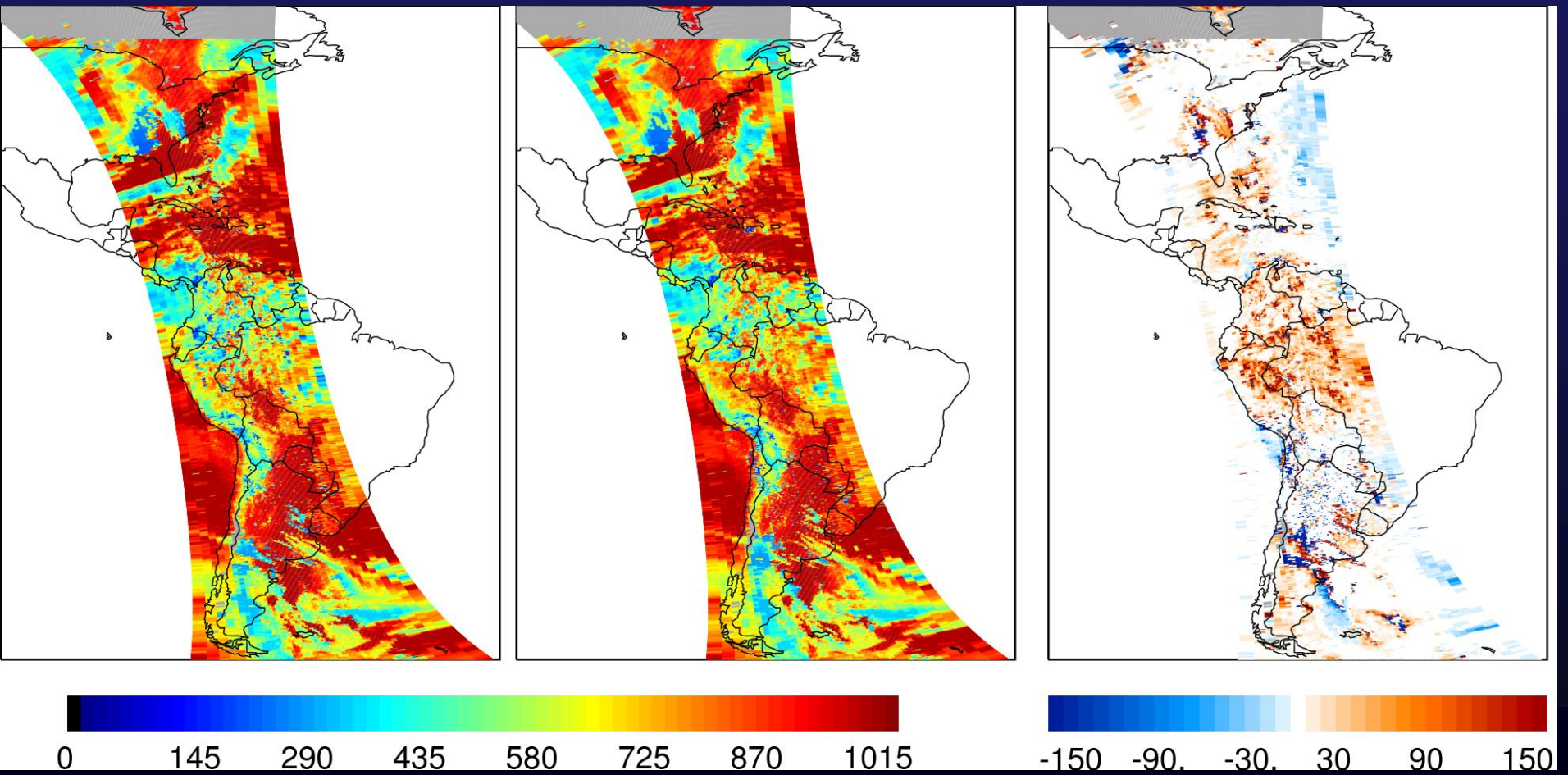
- ↓ LER → ↑ CRF, ↑ LER → ↓ CRF
- No or minimal changes over overcast areas

Cloud Pressure (CP) Comparison

CP with OMI LER

CP with MODIS-derived LER

Difference (MODIS-based – OMI-based)



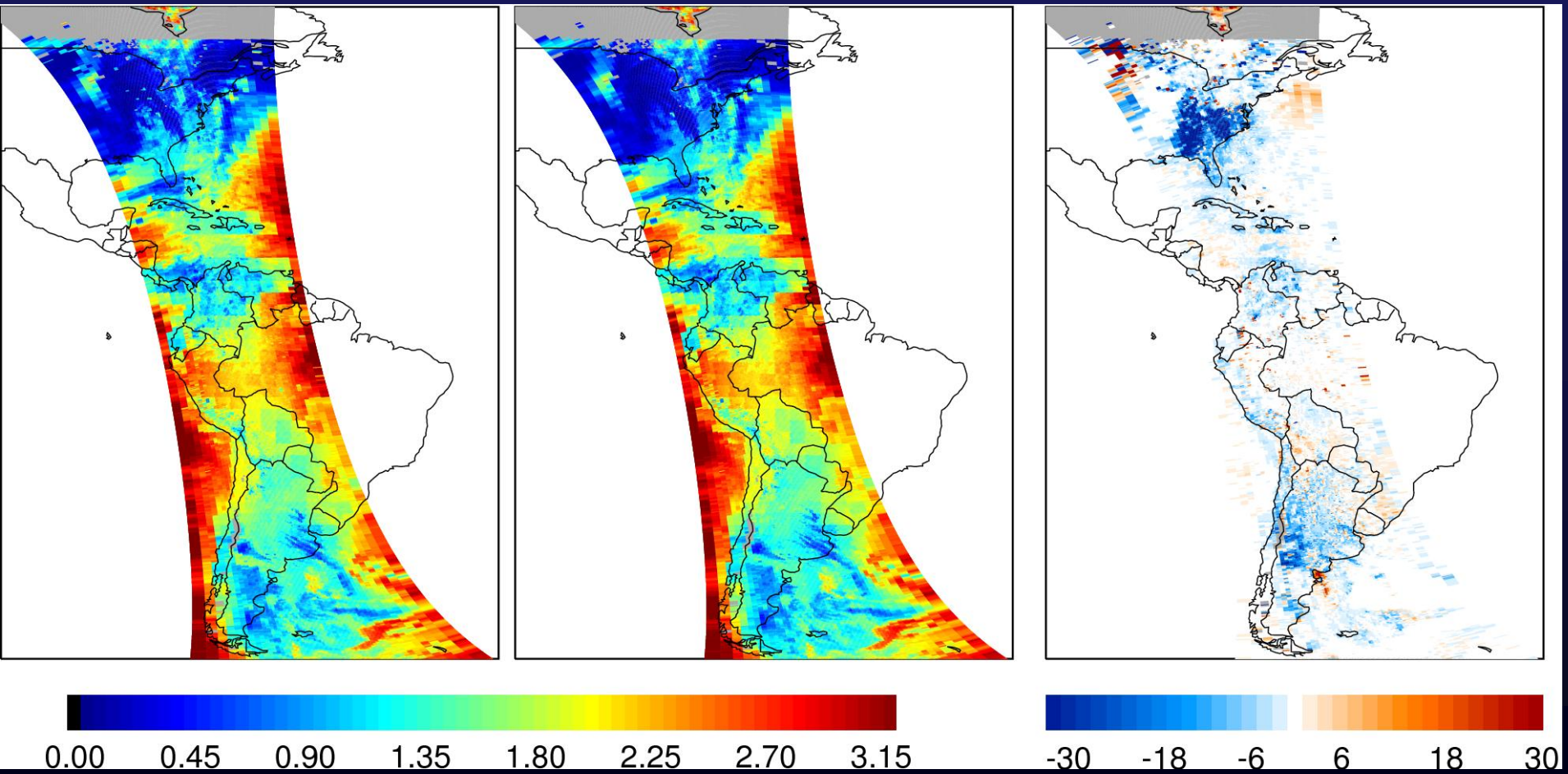
- ↓ LER → ↑ CP, ↑ LER → ↓ CP
- No or minimal changes over overcast areas

NO_2 AMF Comparison

AMF with OMI LER

AMF with MODIS-derived LER

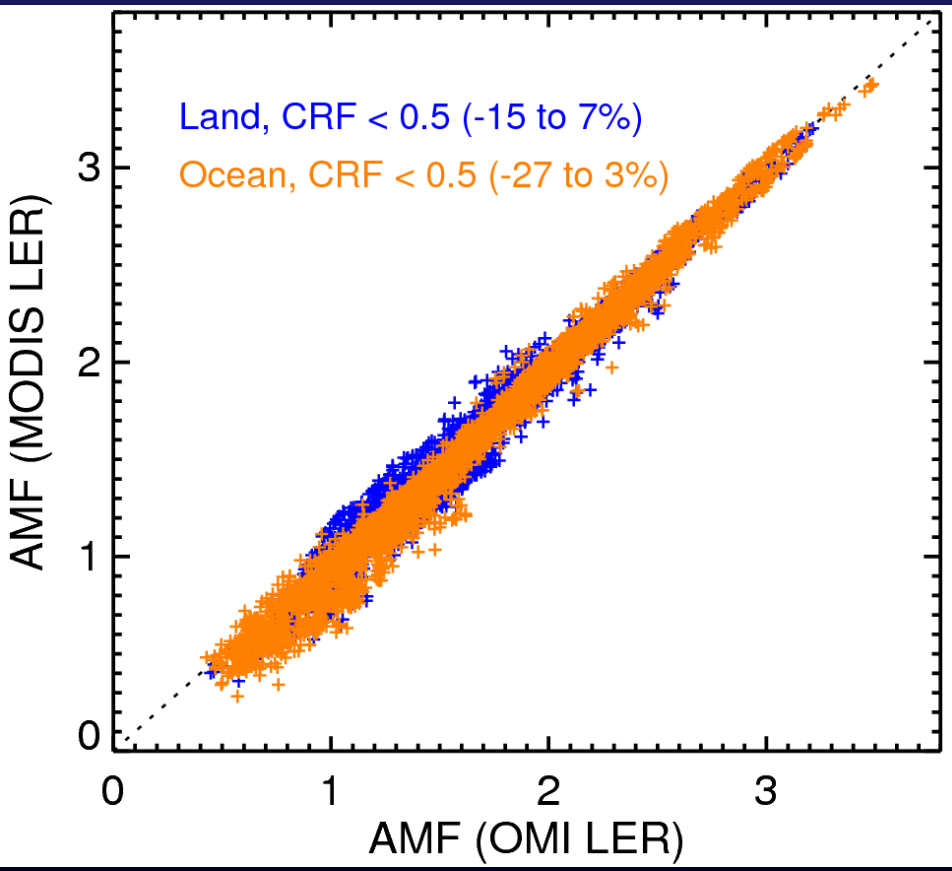
% Difference (MODIS-based – OMI-based)



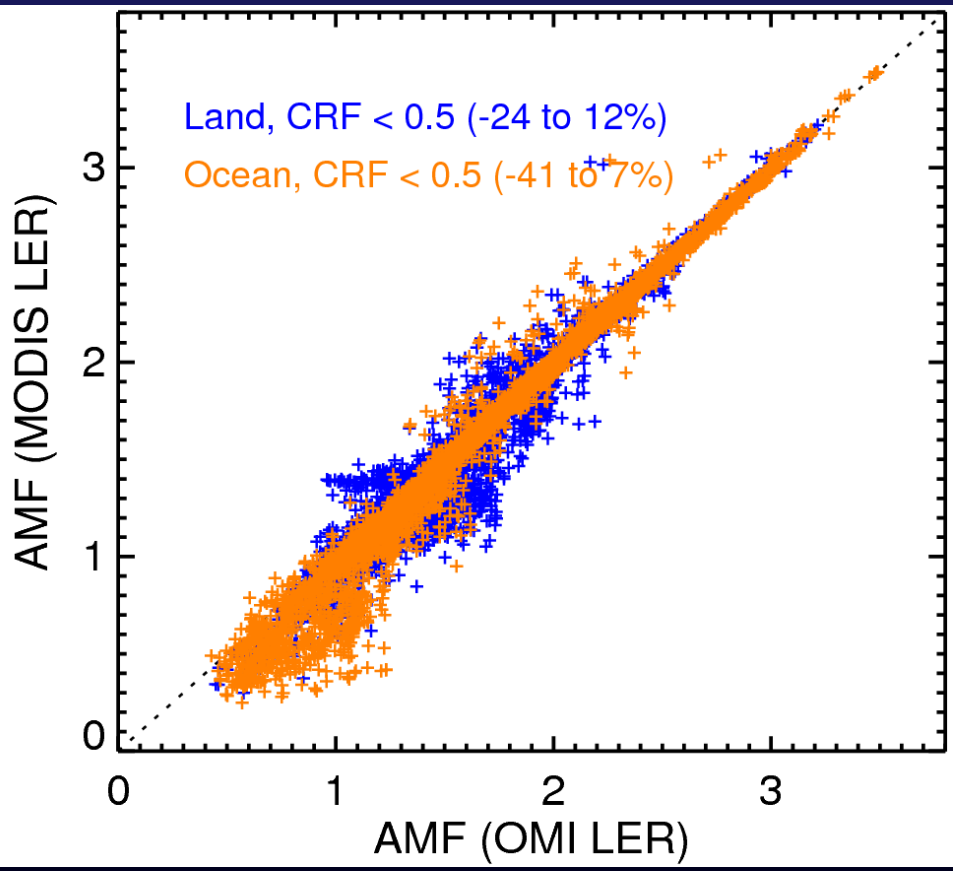
- ↓ LER → ↓ AMF, ↑ LER → ↑ AMF
- Larger difference over polluted areas

NO_2 AMF Comparison

Effect of changes in LER only



Effect of changes in both LER & cloud retrievals

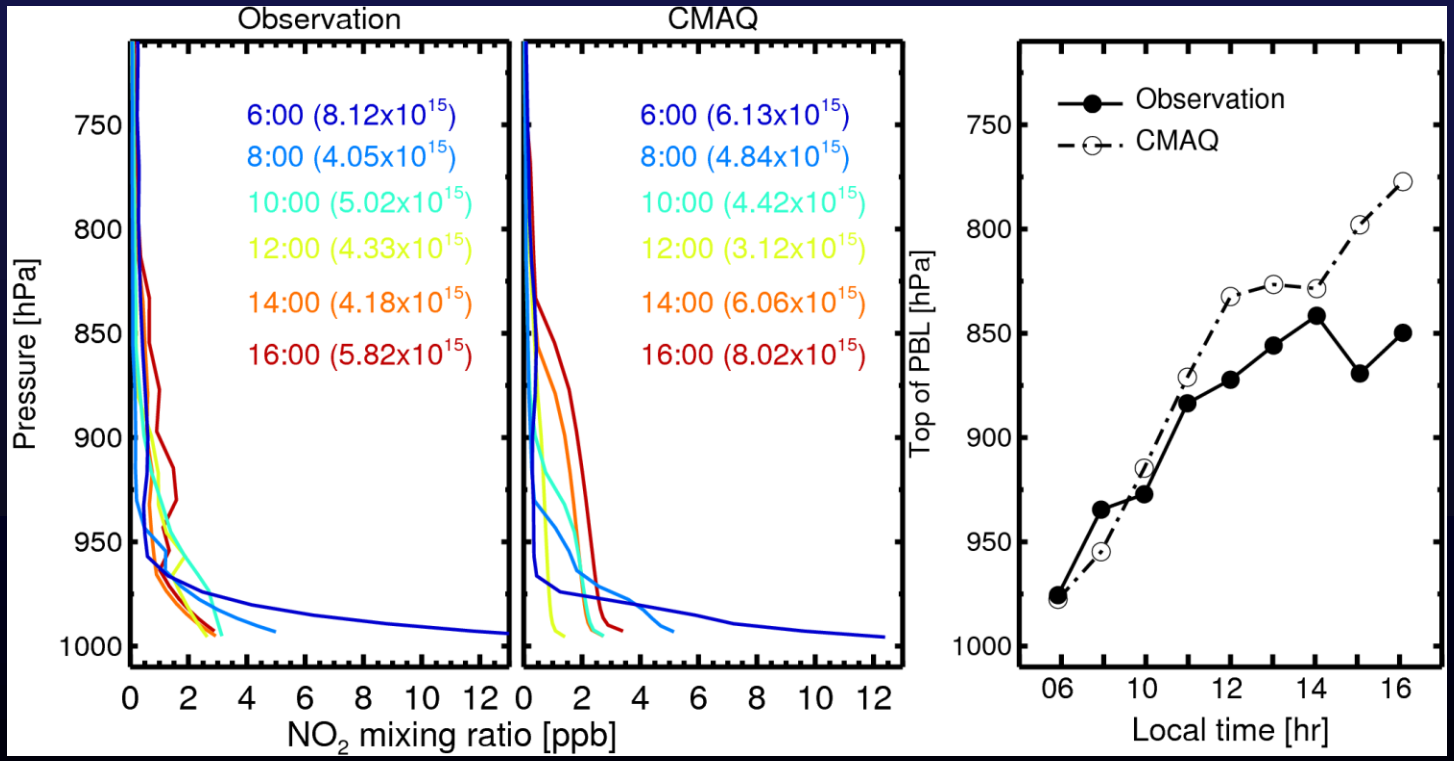


Tropospheric NO_2 Retrievals Are Very Sensitive to A-Priori NO_2 Profiles

$$\mathbf{AMF_{trop}} = \sum_{\mathbf{surf}}^{\mathbf{trop}} \mathbf{w} \times sf$$

- Emissions
- Chemistry
- Dynamics/Transport

Maryland, DISCOVER-AQ (July 2011)



Model Issues

PBL height;

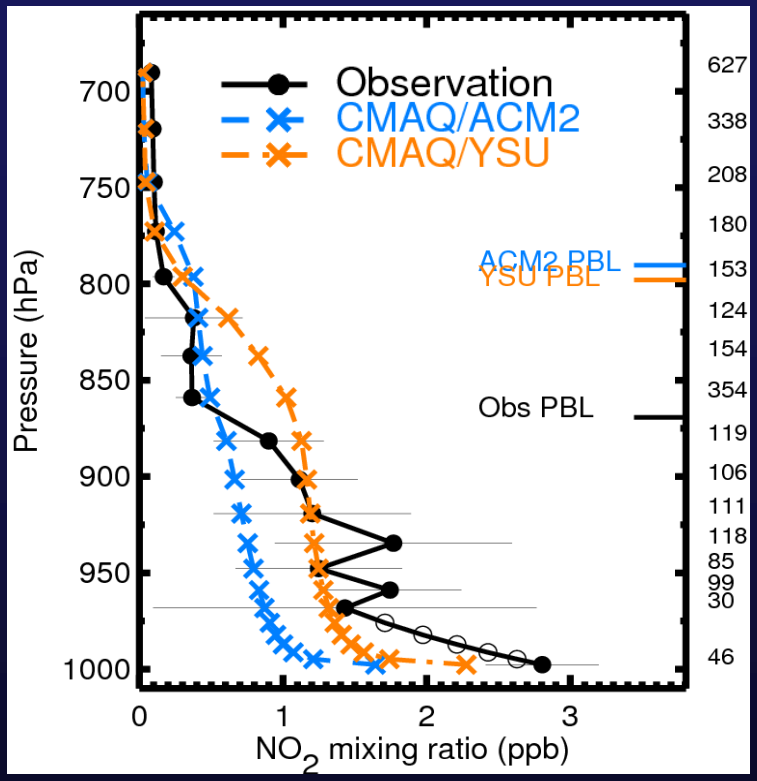
Vertical mixing;

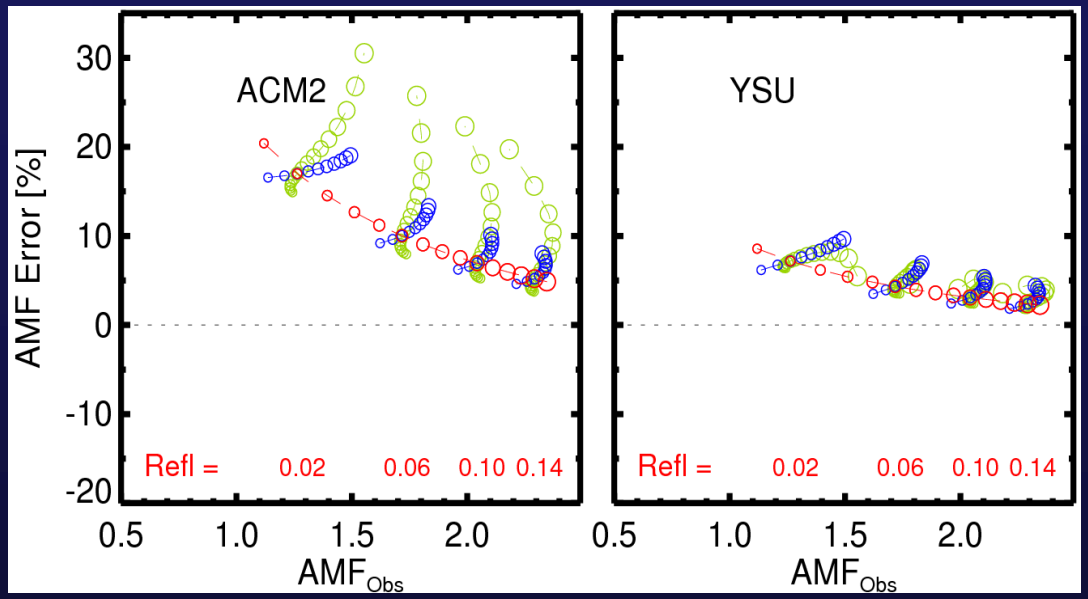
Low free-trop NO_2;

Emissions

AMF & A-Priori NO_2 Profiles: Mixing Scheme & PBL Heights

July average NO_2 profiles for 3 PM local time (DISCOVER-AQ, Maryland, 2011)





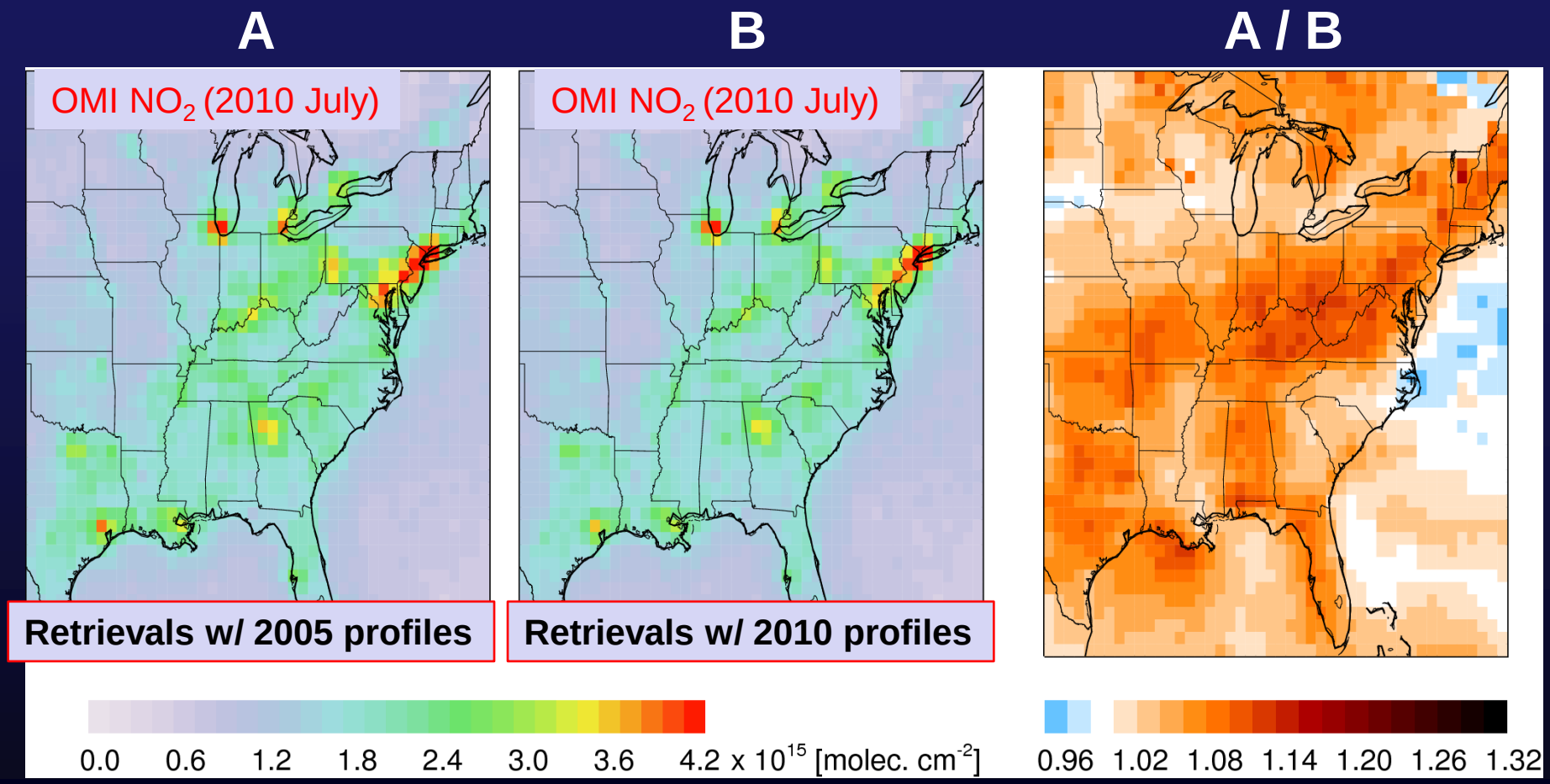
Surface reflectivities: 0.1 to 0.15 at 0.01 steps

Solar zenith angles: 10° to 85° at 5° steps

Aerosol optical depths: 0.1 to 0.9 at 0.1 steps

- Errors in PBL heights and differences in mixing scheme can lead to errors of up to 25%. Different errors for different PBL schemes.

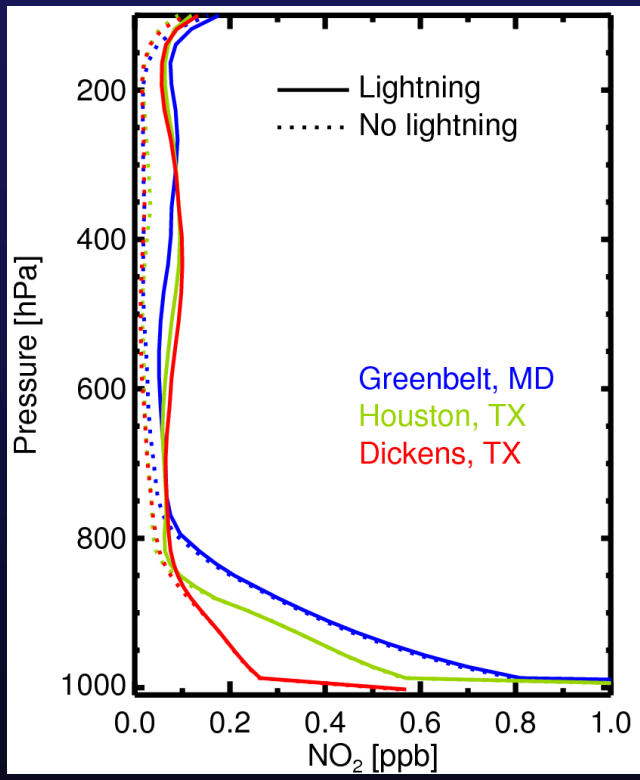
Sensitivity of AMF to A-Priori NO_2 Profiles: Emission Inventory



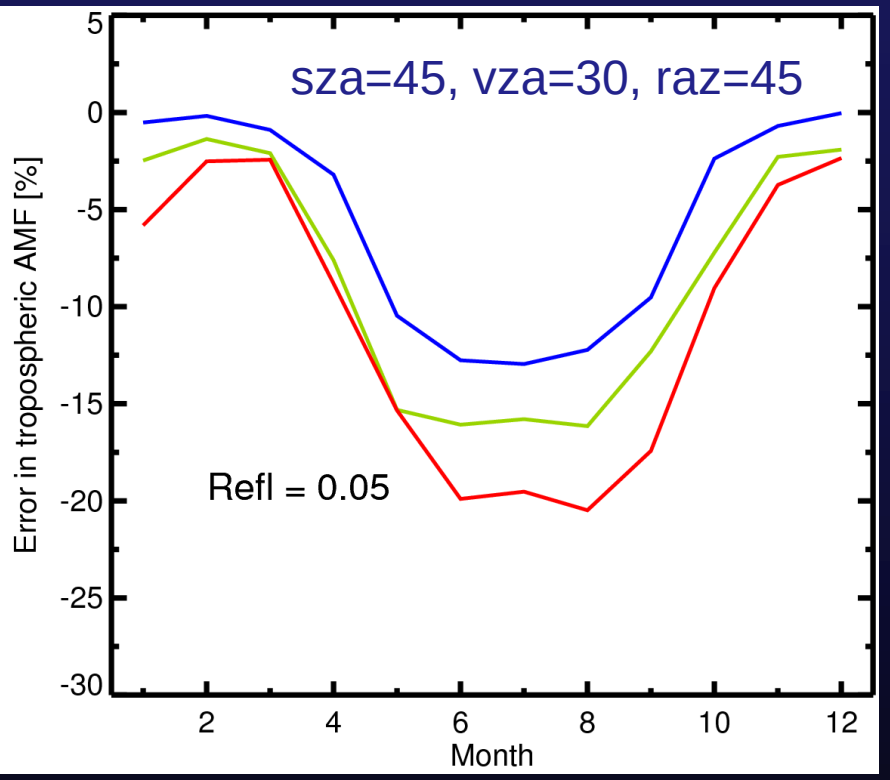
- Profiles based on outdated or inaccurate emissions can introduce significant retrieval errors.

AMF and A-Priori NO_2 Profiles: Too Low Free-tropospheric NO_2

- How are retrievals affected if free-tropospheric NO_2 is too low? Example based on missing lightning NO_x emissions.



GMI simulation for June, 2005

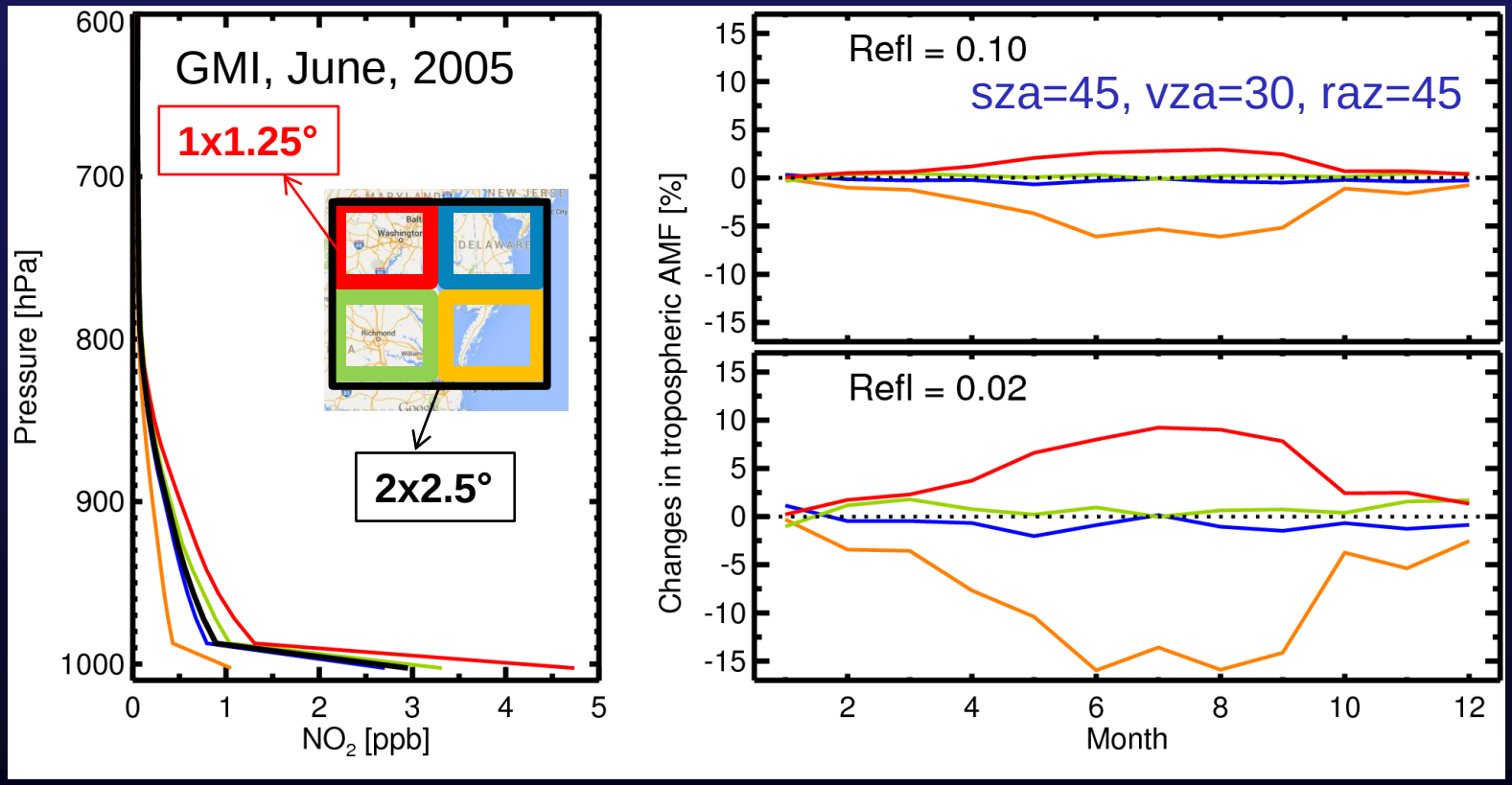


$(AMF_{NoL} - AMF_L)/AMF_L$

- Neglecting lightning NO_x changes profiles, AMFs, and therefore NO_2 columns

AMF and A-Priori NO_2 Profiles: Model Spatial Resolution

Short-lifetime of NO_2 lead to steep gradient in NO_2 concentration near sources, so resolution matters.



$(AMF_{2x2.5} - AMF_{1x1.25})/AMF_{1x1.25}$

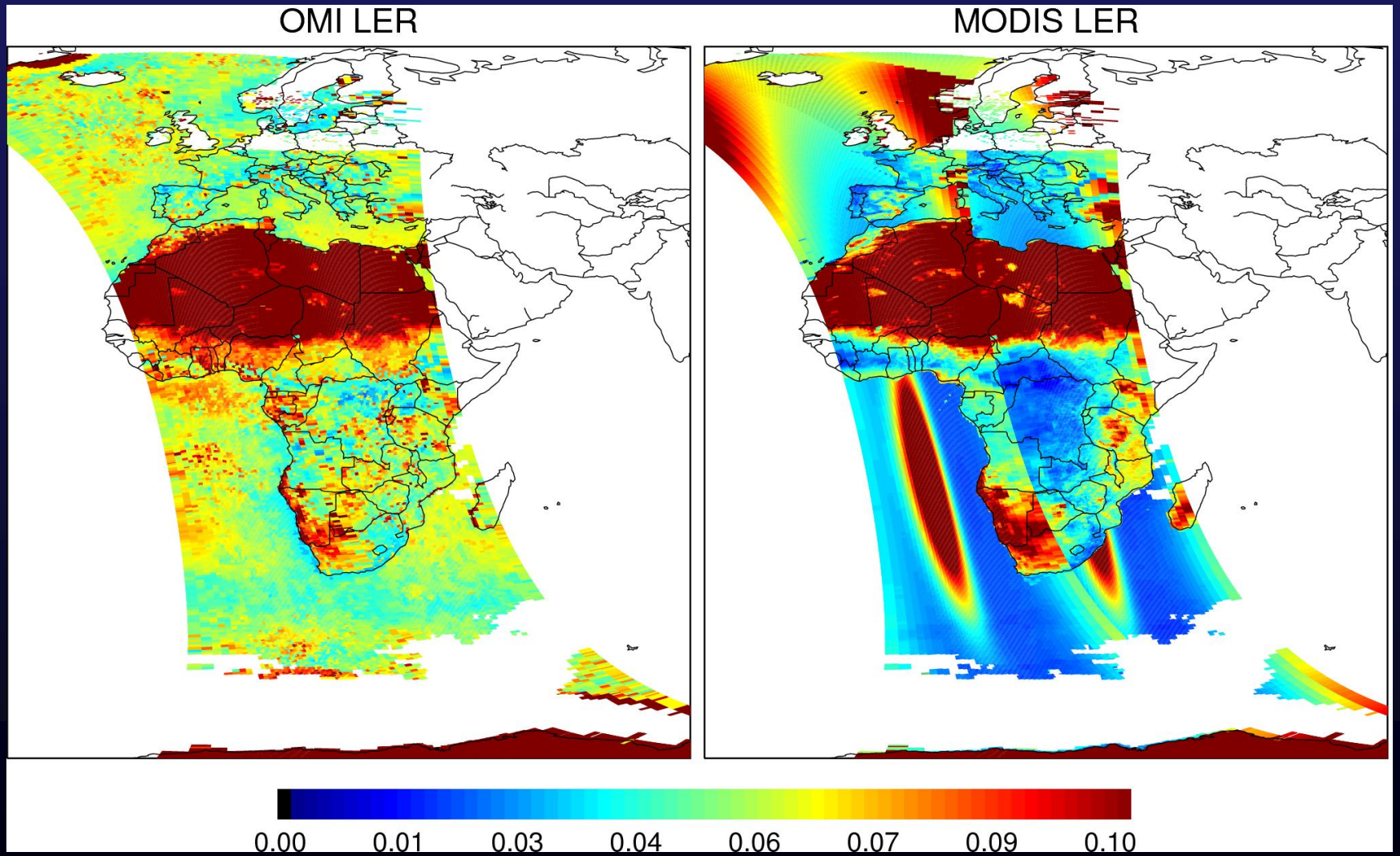
- A factor of 4 increase in resolution changes retrievals by up to 15% in some locations.

Conclusions

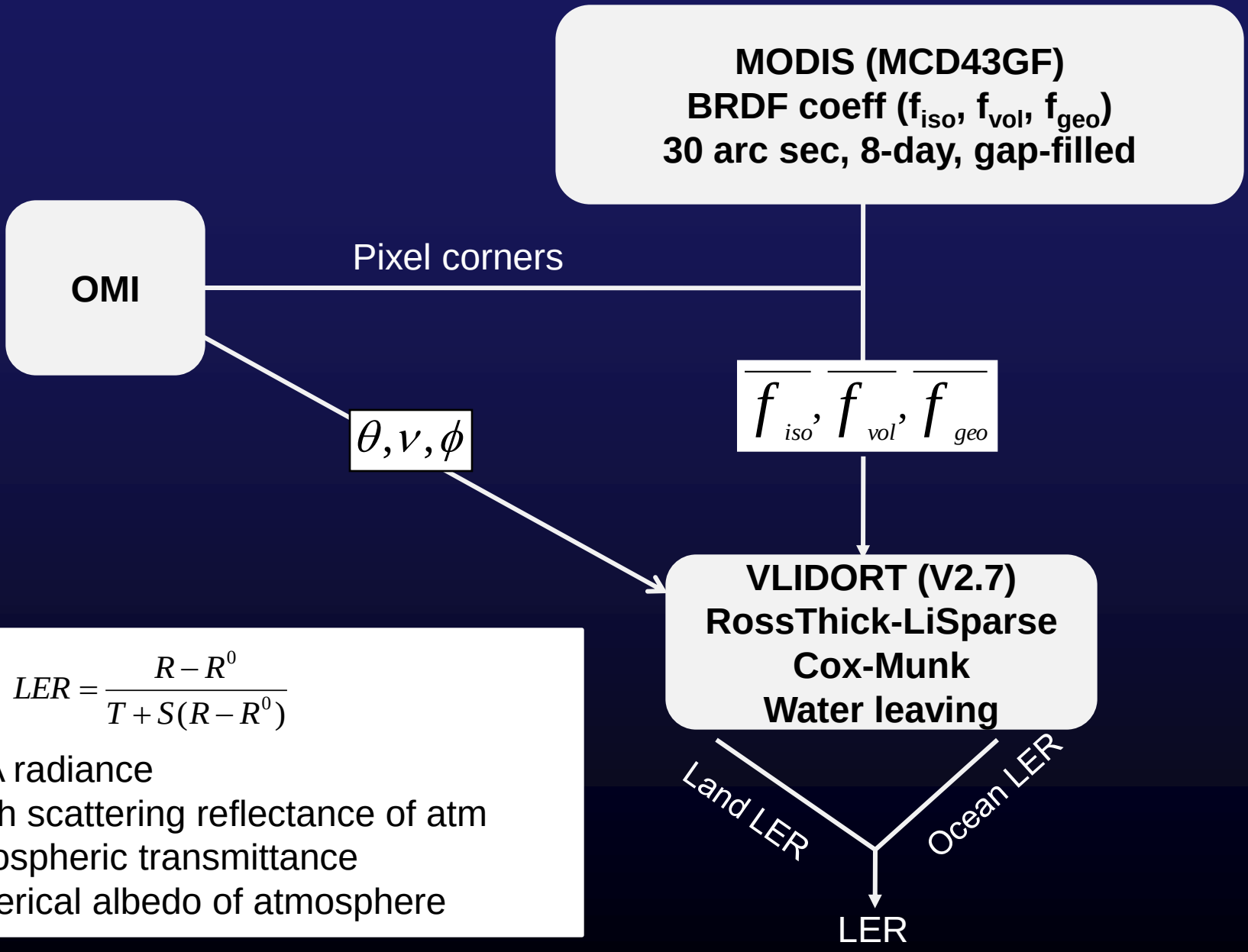
- Gemeotry-dependent LER product for TEMPO would help improve cloud and trace-gas retrievals;

- There are several issues on model-based a-priori NO_2 profiles that need to be carefully evaluated for application to TEMPO.

AMF & Surface Reflectivity: Sensitivity



AMF & Surface Reflectivity: Our Approach



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