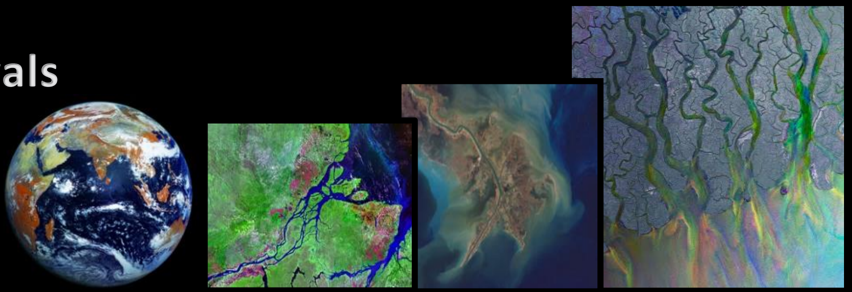
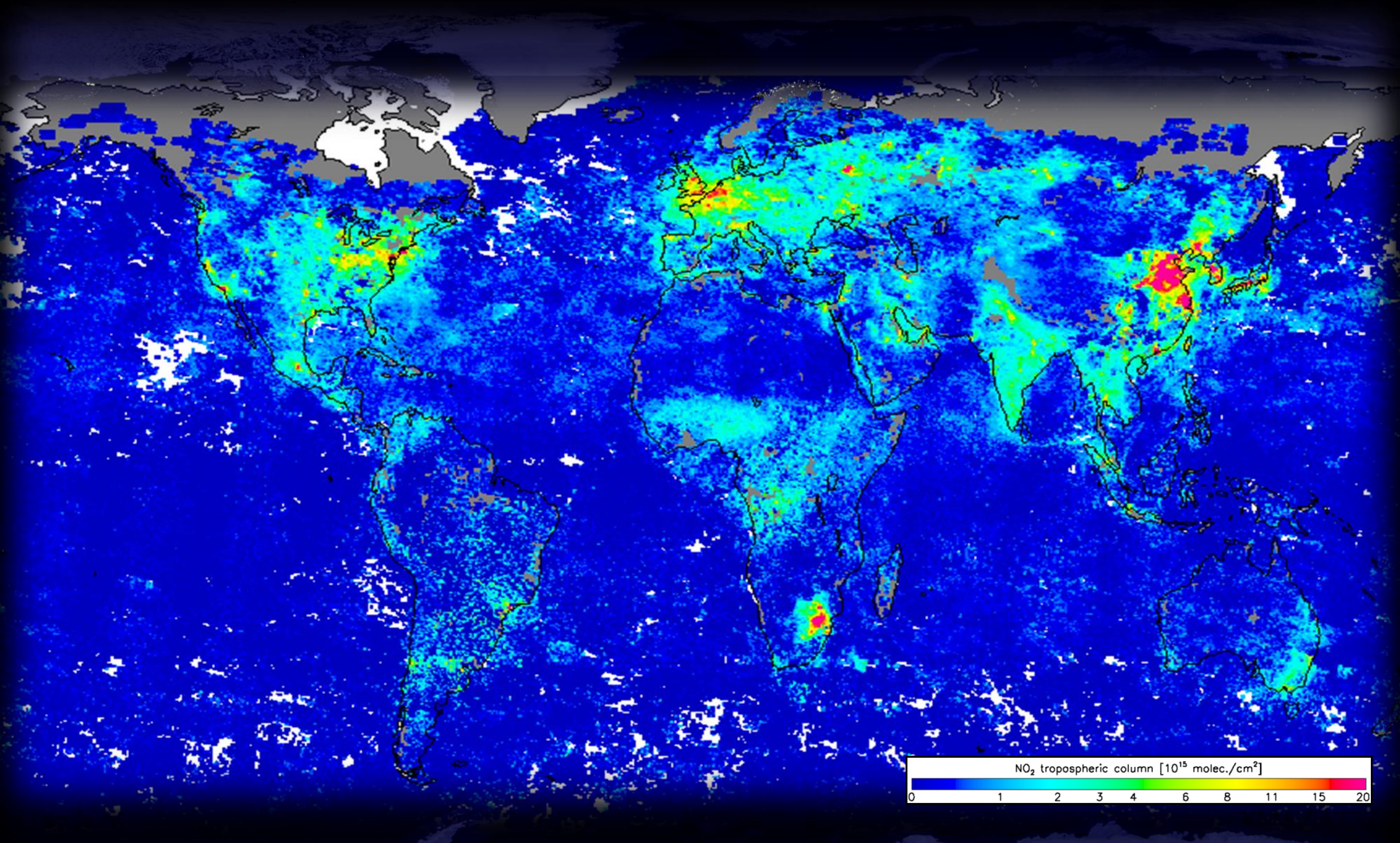
Satellite image of Earth's city lights-Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS). The brightest areas of the Earth are the most urbanized (http://www.earthobservatory.nasa.gov/IOTD/view.php?id=896)

Atmospheric NO_2 dynamics

and impact on coastal ocean color retrievals



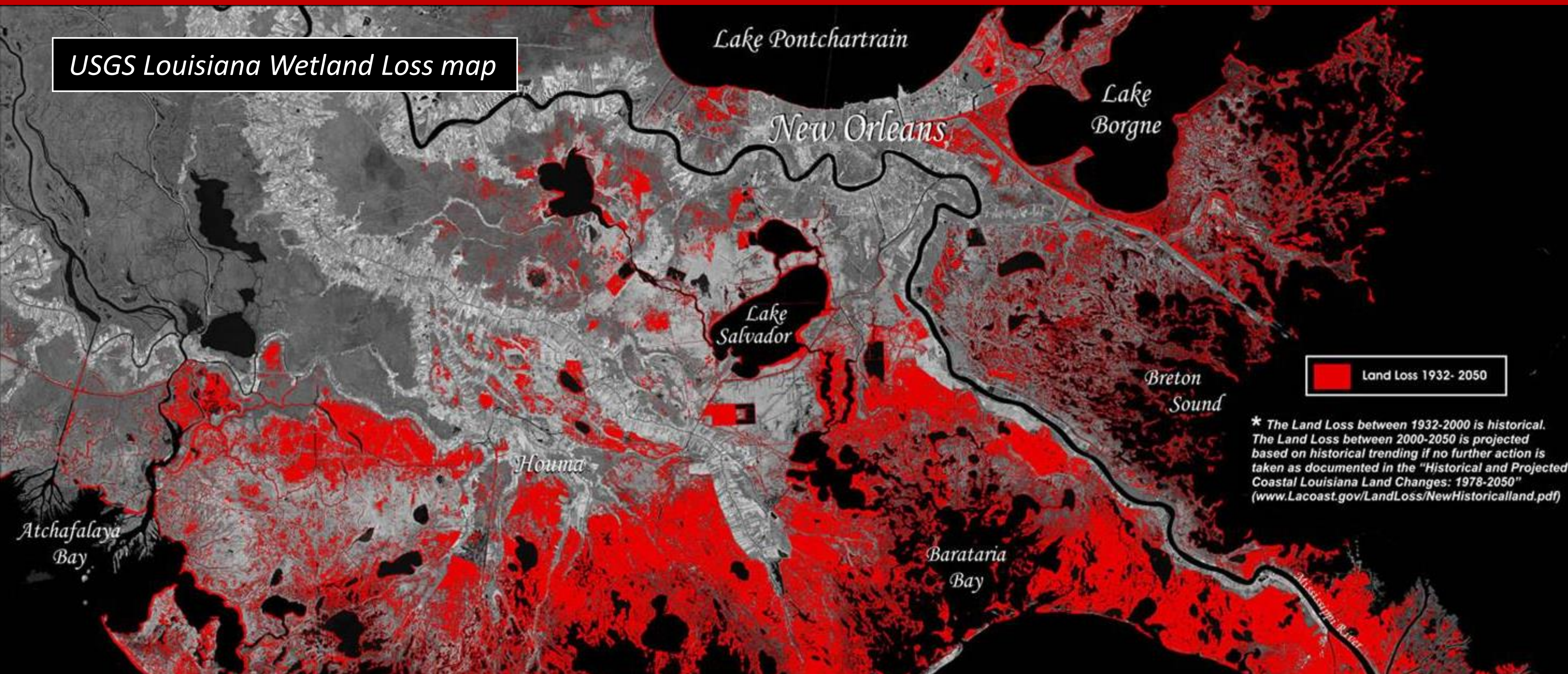
M. Tzortziou, J. Herman, Z. Ahmad, C. Loughner

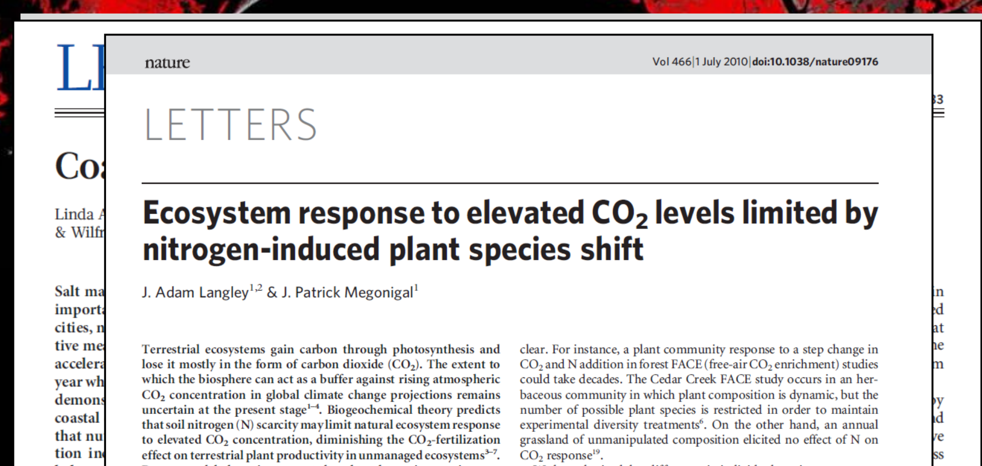


Major sources of NOx emissions: motor vehicles, electric utilities, other industrial, commercial, residential sources that burn fuels

Trospospheric Nitrogen Dioxide (NO_2) data from SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric CHartographY) - Monthly for April 2007. Measurements of tropospheric NO_2 are a good indicator of the geographical location of anthropogenic air pollution

Improved Atmospheric Correction of Satellite Ocean Color





nature Vol 466|1 July 2010|doi:10.1038/nature09176

LETTERS

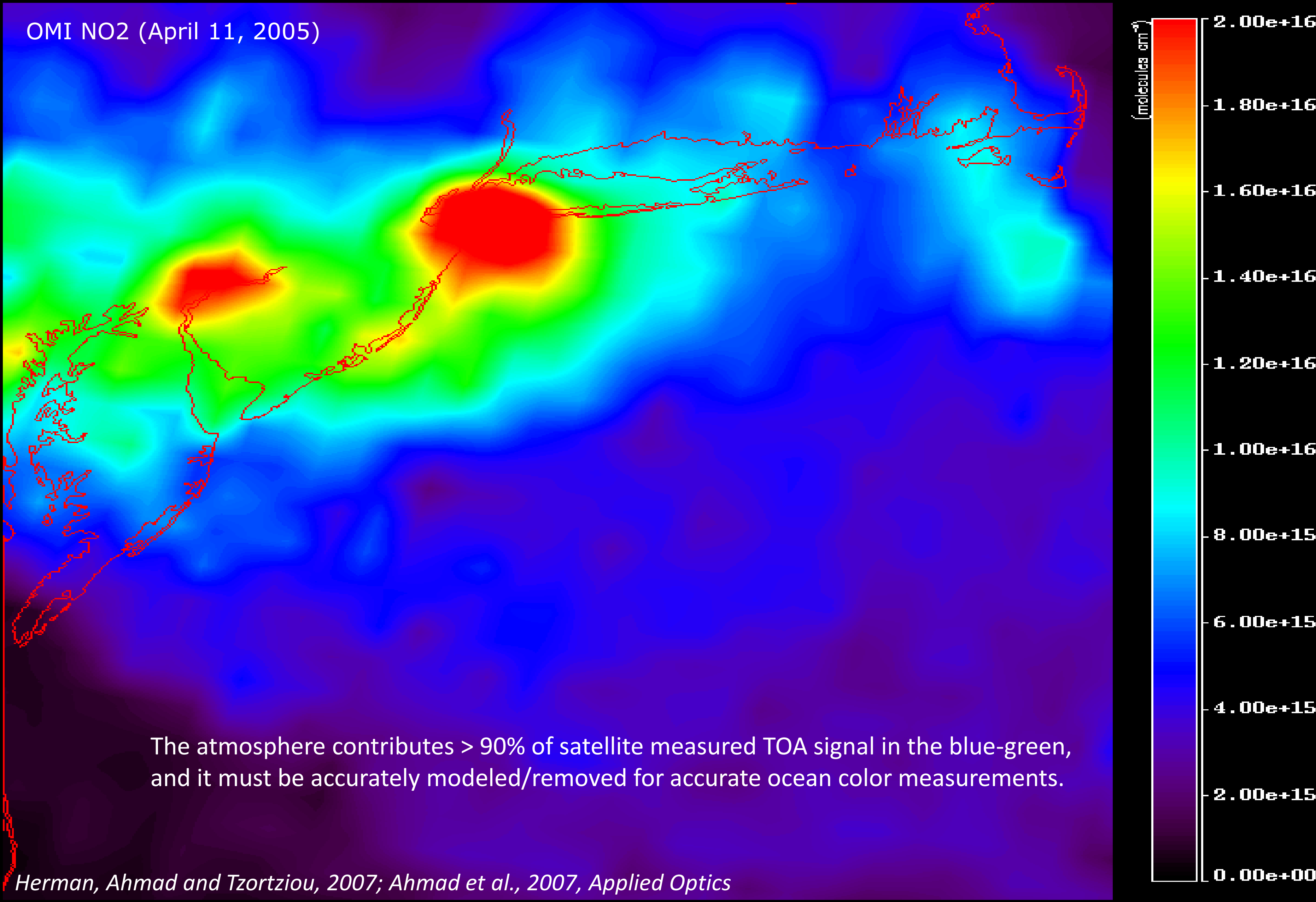
Ecosystem response to elevated CO_2 levels limited by nitrogen-induced plant species shift

J. Adam Langley[1,2] & J. Patrick Megonigal[1]

Terrestrial ecosystems gain carbon through photosynthesis and lose it mostly in the form of carbon dioxide (CO_2). The extent to which the biosphere can act as a buffer against rising atmospheric CO_2 concentration in global climate change projections remains uncertain at the present stage[1–4]. Biogeochemical theory predicts that soil nitrogen (N) scarcity may limit natural ecosystem response to elevated CO_2 concentration, diminishing the CO_2-fertilization effect on terrestrial plant productivity in unmanaged ecosystems[5–7]. Recent models have incorporated such carbon–nitrogen interac-

clear. For instance, a plant community response to a step change in CO_2 and N addition in forest FACE (free-air CO_2 enrichment) studies could take decades. The Cedar Creek FACE study occurs in an herbaceous community in which plant composition is dynamic, but the number of possible plant species is restricted in order to maintain experimental diversity treatments[6]. On the other hand, an annual grassland of unmanipulated composition elicited no effect of N on CO_2 response[19].

We hypothesized that differences in individual species responses to



The atmosphere contributes > 90% of satellite measured TOA signal in the blue-green, and it must be accurately modeled/removed for accurate ocean color measurements.

Herman, Ahmad and Tzortziou, 2007; Ahmad et al., 2007, Applied Optics

Nitrogen Dioxide Absorption Cross sections (at 293 °K)

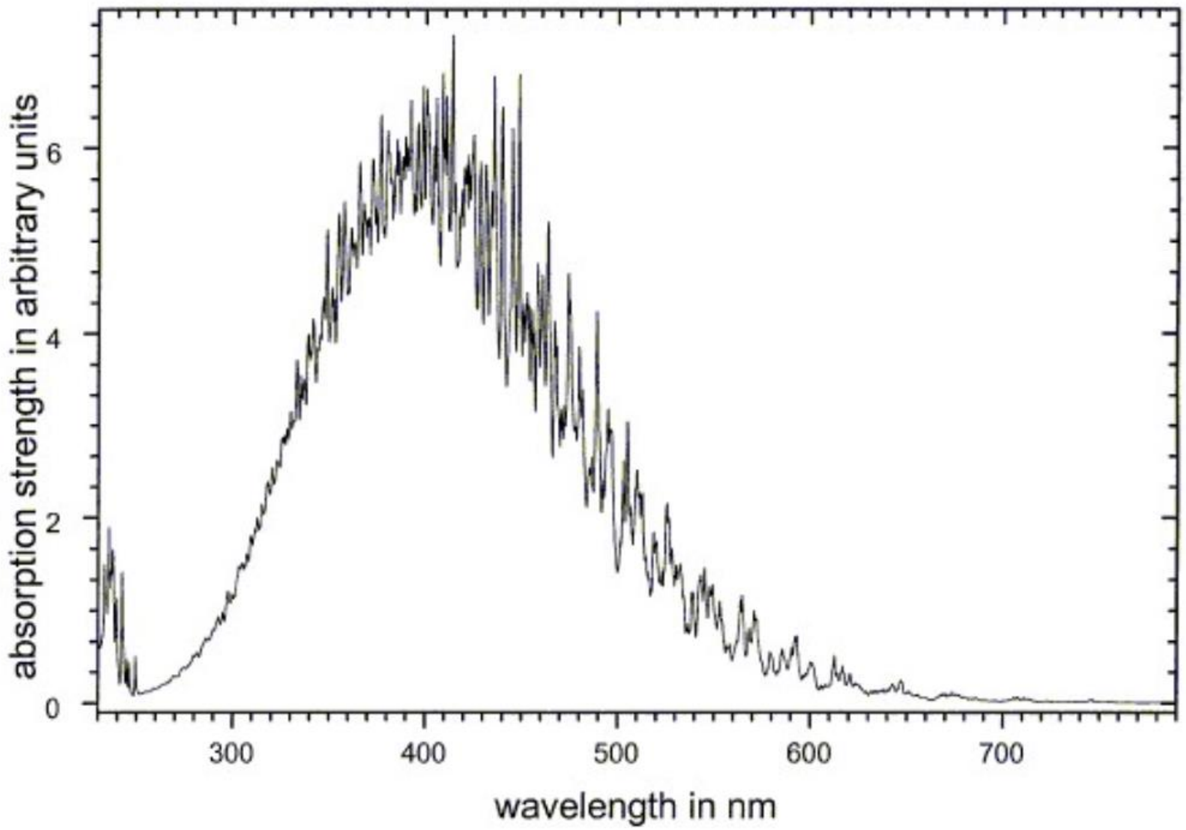


Fig. 1. Relative NO_2 spectrum at 293 K measured by GOME FM between 231–794 nm. The spectral resolution is 0.2 nm at wavelengths below and 0.3 nm above 400 nm.

How much?

How variable?

Atmospheric NO_2 dynamics and impacts on coastal ocean color

HyspIRI
2015 Workshop
Greenbelt, MD, June 3-5

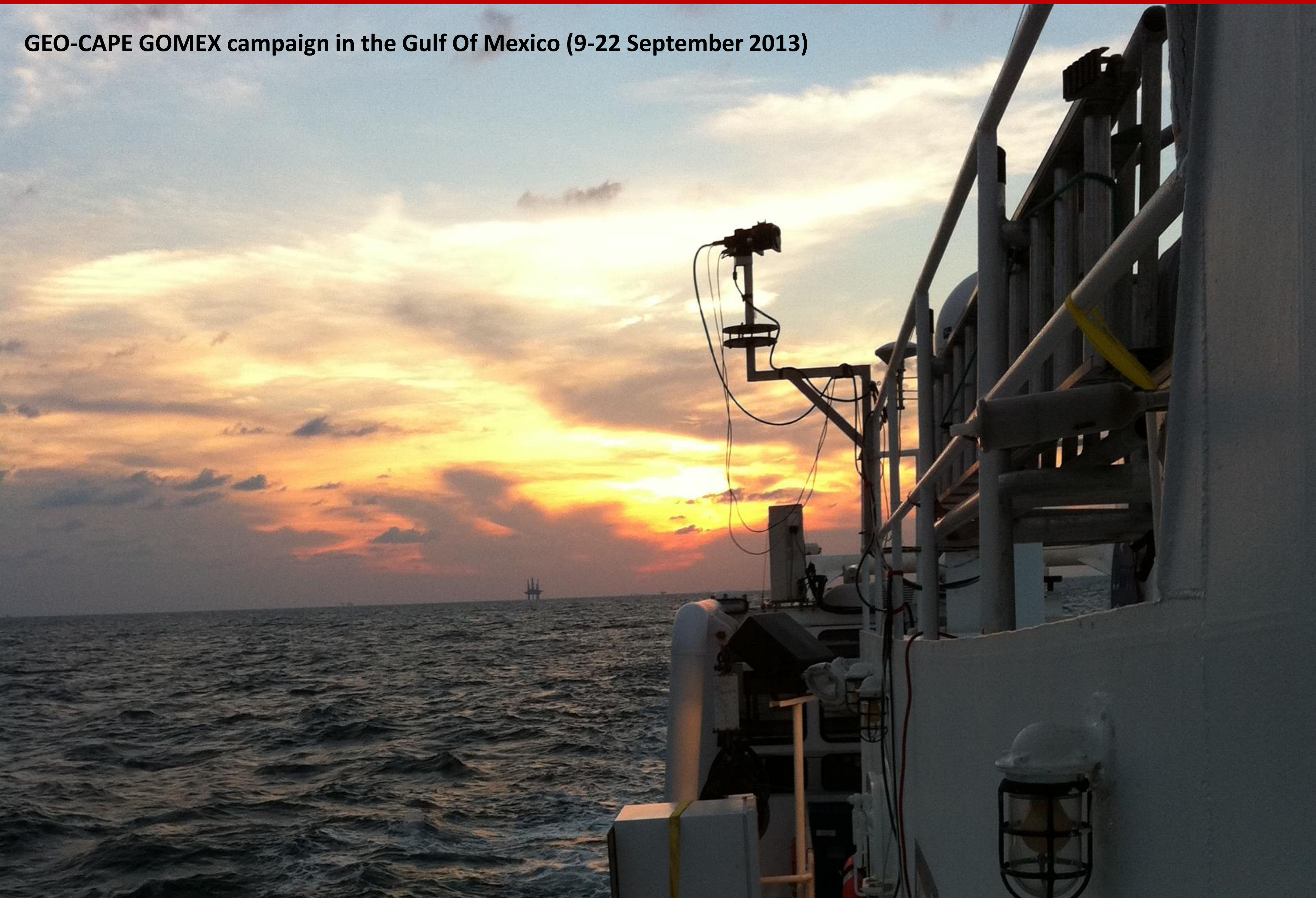
GEO-CAPE CBODAQ Campaign in the Chesapeake Bay (11-20 July 2011)

CBODAQ: Chesapeake Bay Oceanographic Campaign with Discover-AQ

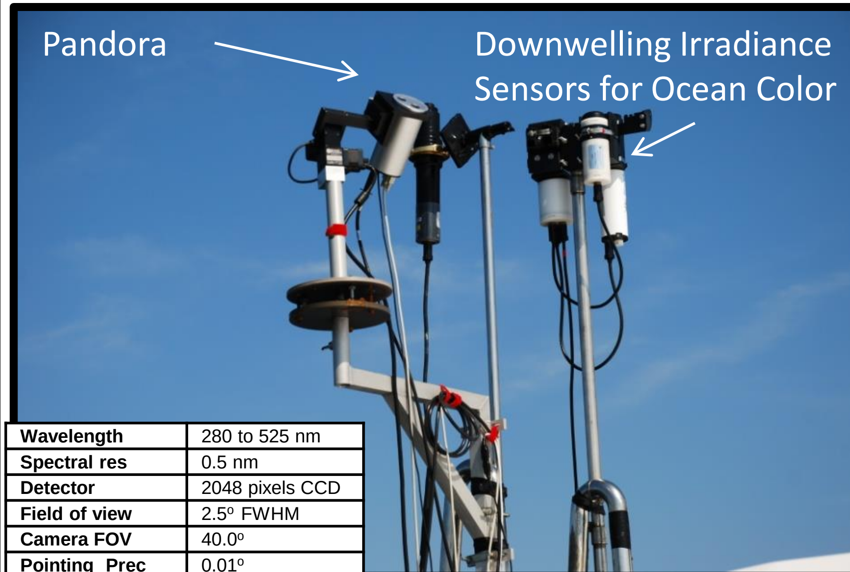
NOAA Vessel SRVx - National Marine Sanctuary Test and Evaluation Vessel R8501

NASA aircraft campaign DISCOVER-AQ (Deriving Information on Surface Conditions from COlumn and VERtically Resolved Observations Relevant to Air Quality

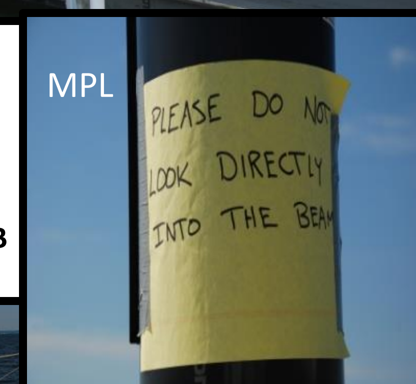
GEO-CAPE GOMEX campaign in the Gulf Of Mexico (9-22 September 2013)



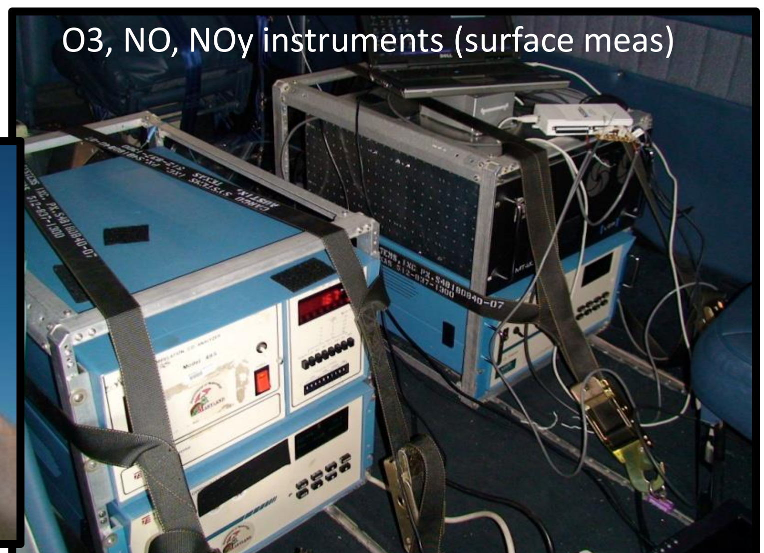
Measurements of atmospheric composition and variability



Wavelength	280 to 525 nm
Spectral res	0.5 nm
Detector	2048 pixels CCD
Field of view	2.5º FWHM
Camera FOV	40.0º
Pointing Prec	0.01º
ND Filter	ND1 to ND3



NRB
PBL



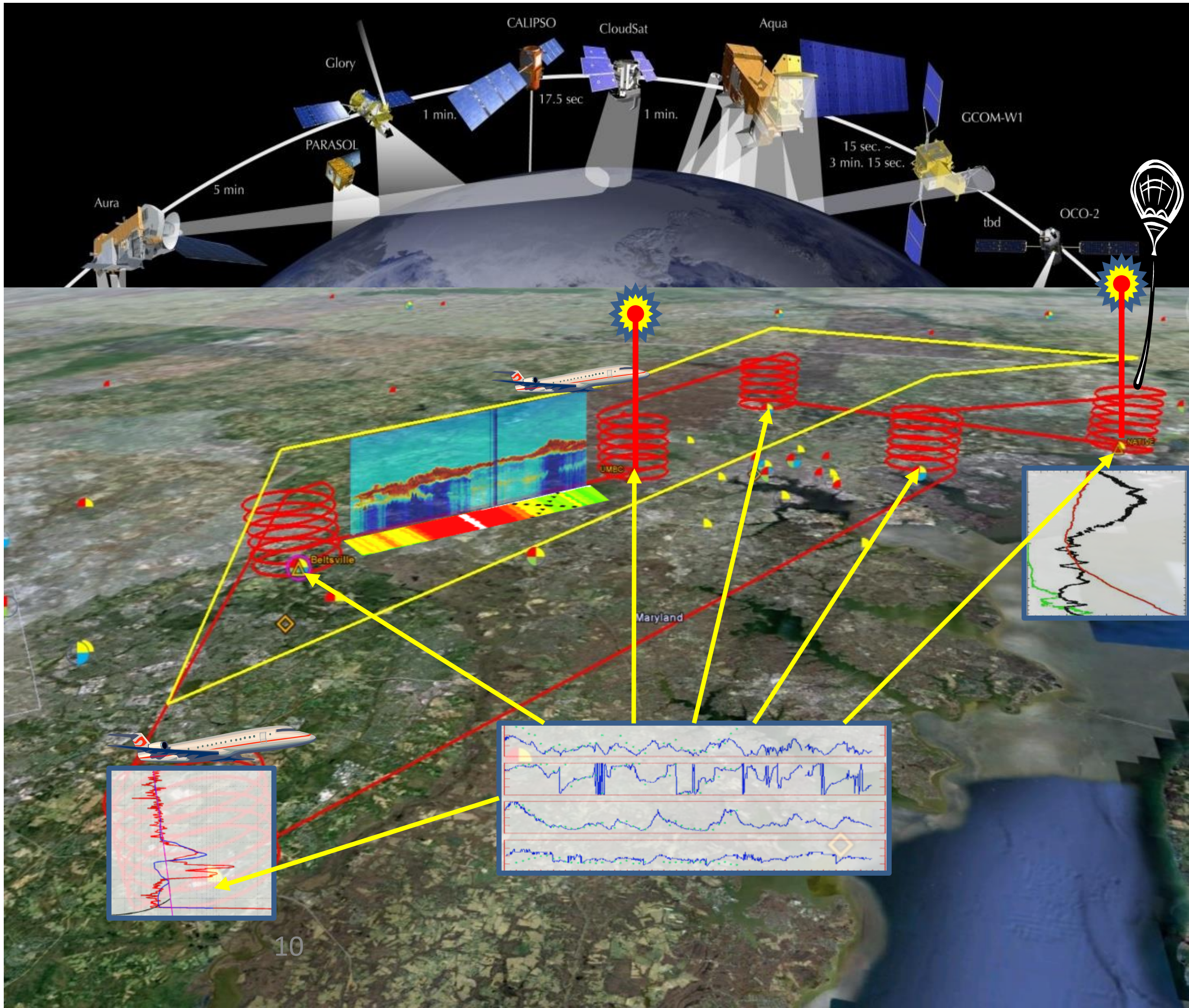
DISCOVER-AQ: Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality

Three major observational components:

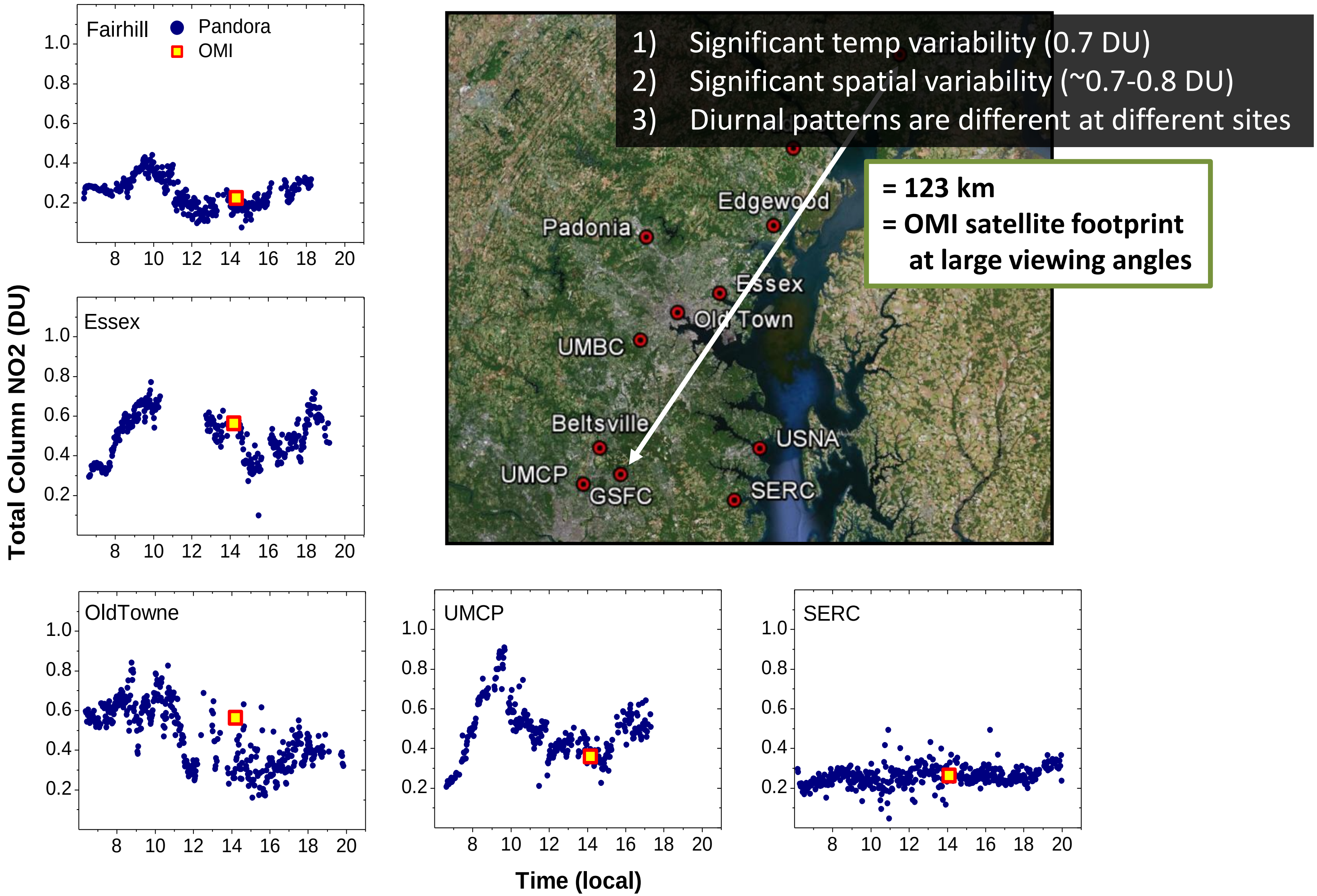
<u>NASA UC-12 (Remote sensing)</u>
Continuous mapping of aerosols with HSRL and trace gas columns with ACAM

<u>NASA P-3B (in situ meas.)</u>
In situ profiling of aerosols and trace gases over surface measurement sites

<u>Ground sites</u>
In situ trace gases and aerosols
Remote sensing of trace gas and aerosol columns
Ozonesondes
Aerosol lidar observations



Spatial & temporal variability in $TCNO_2$ - Washington DC/Chesapeake Bay area (July 18, 2011)



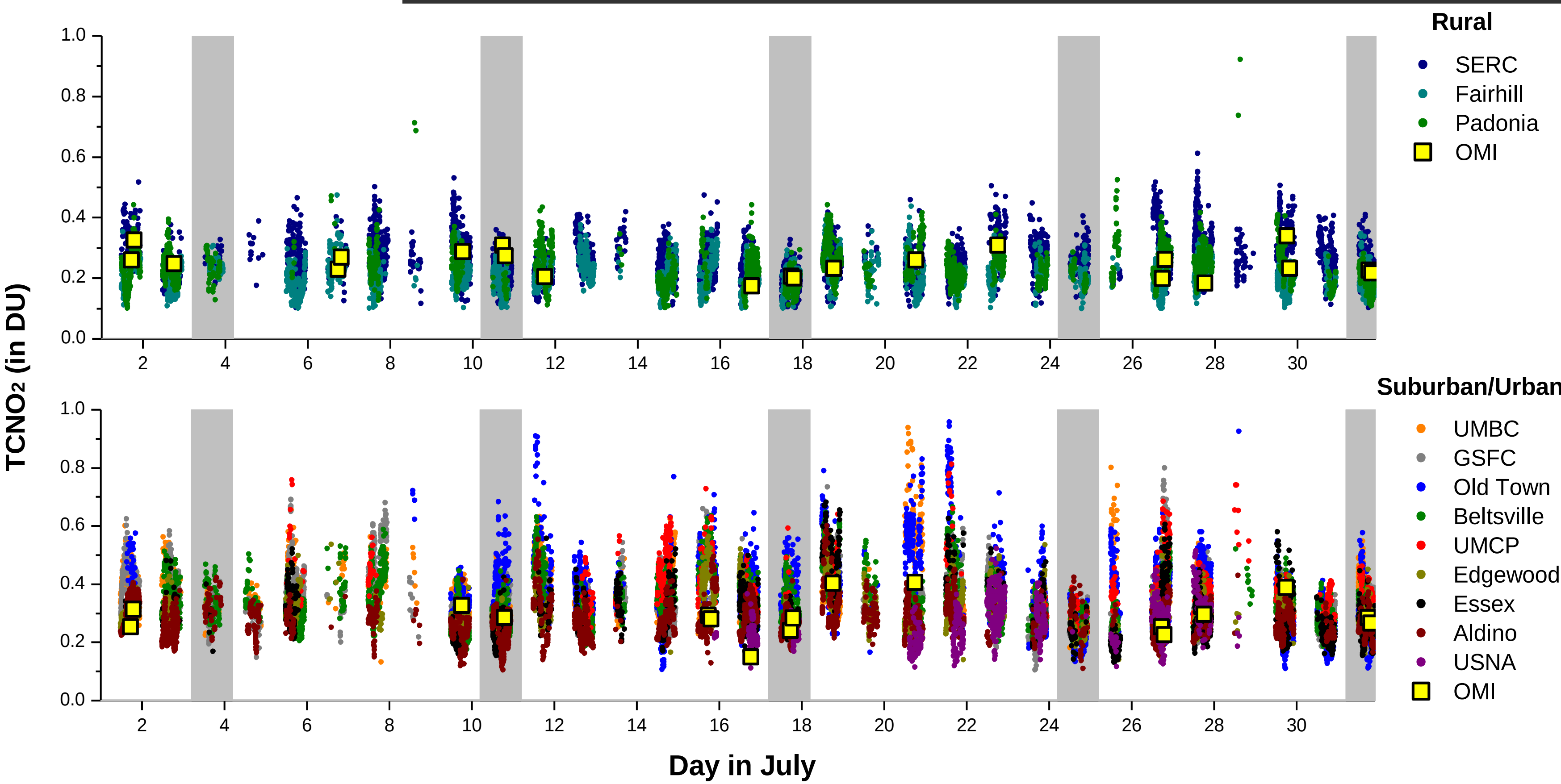
1) Significant temp variability (0.7 DU)
2) Significant spatial variability (~0.7-0.8 DU)
3) Diurnal patterns are different at different sites

= 123 km
= OMI satellite footprint at large viewing angles

Tzortziou et al 2014, JGR-Oceans, 119, 3834–3854

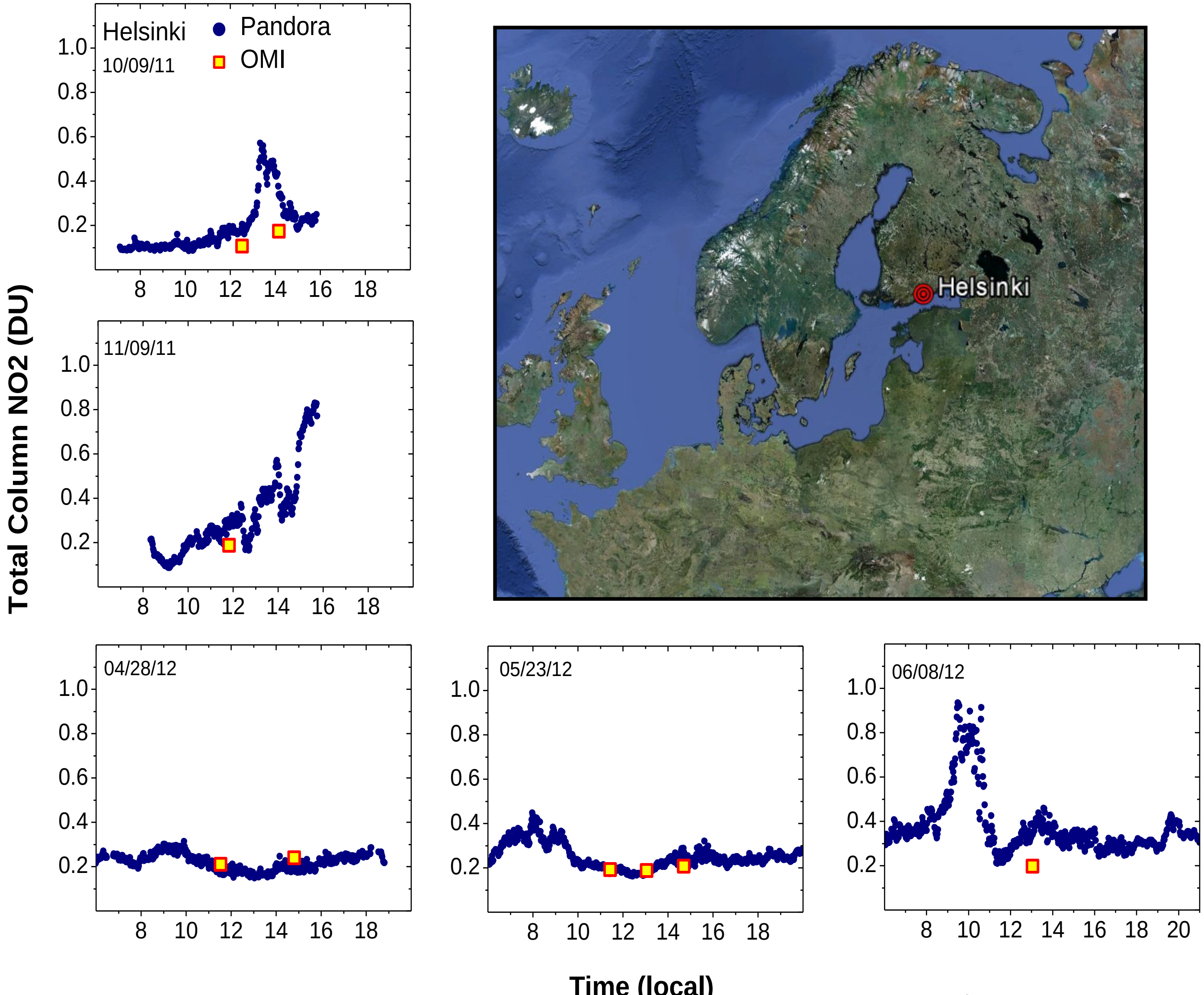
Spatial & temporal variability in $TCNO_2$ - Washington DC/Chesapeake Bay area (July 2011)

1) OMI does not capture spatial variability in NO2 (rural vs urban sites)
2) OMI does not capture temporal variability in NO2 (diurnal or weekly patterns)



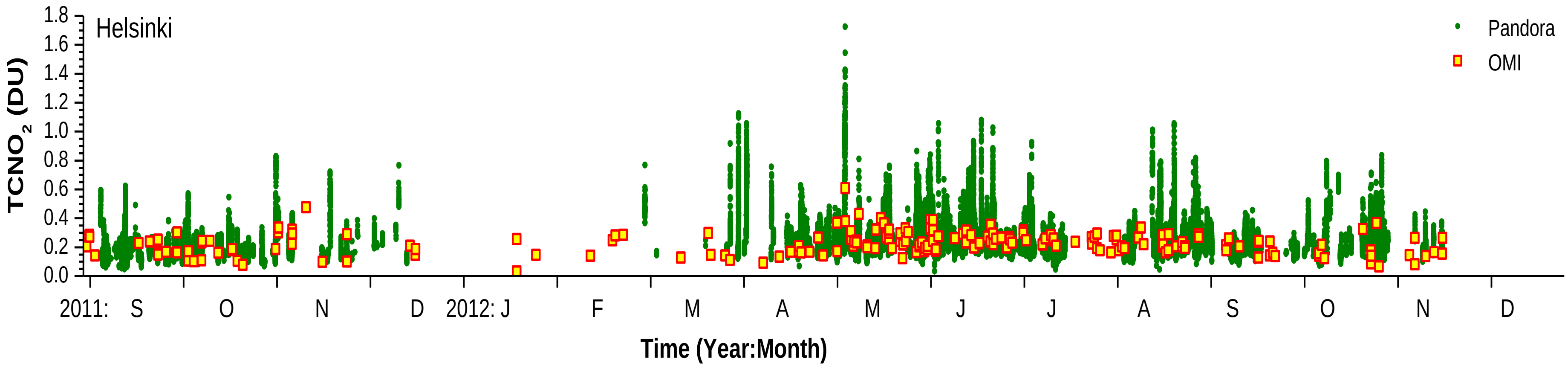
Tzortziou et al 2014, JGR-Oceans, 119, 3834–3854

Spatial & temporal variability in $TCNO_2$ – Helsinki Finland



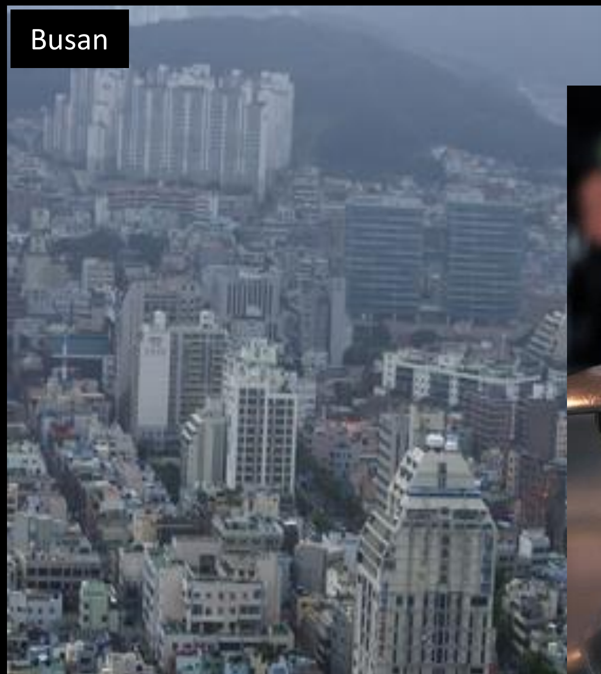
Tzortziou et al 2014, JGR-Oceans, 119, 3834–3854

Spatial & temporal variability in $TCNO_2$ – Helsinki Finland (Sept 2011 – Nov 2012)

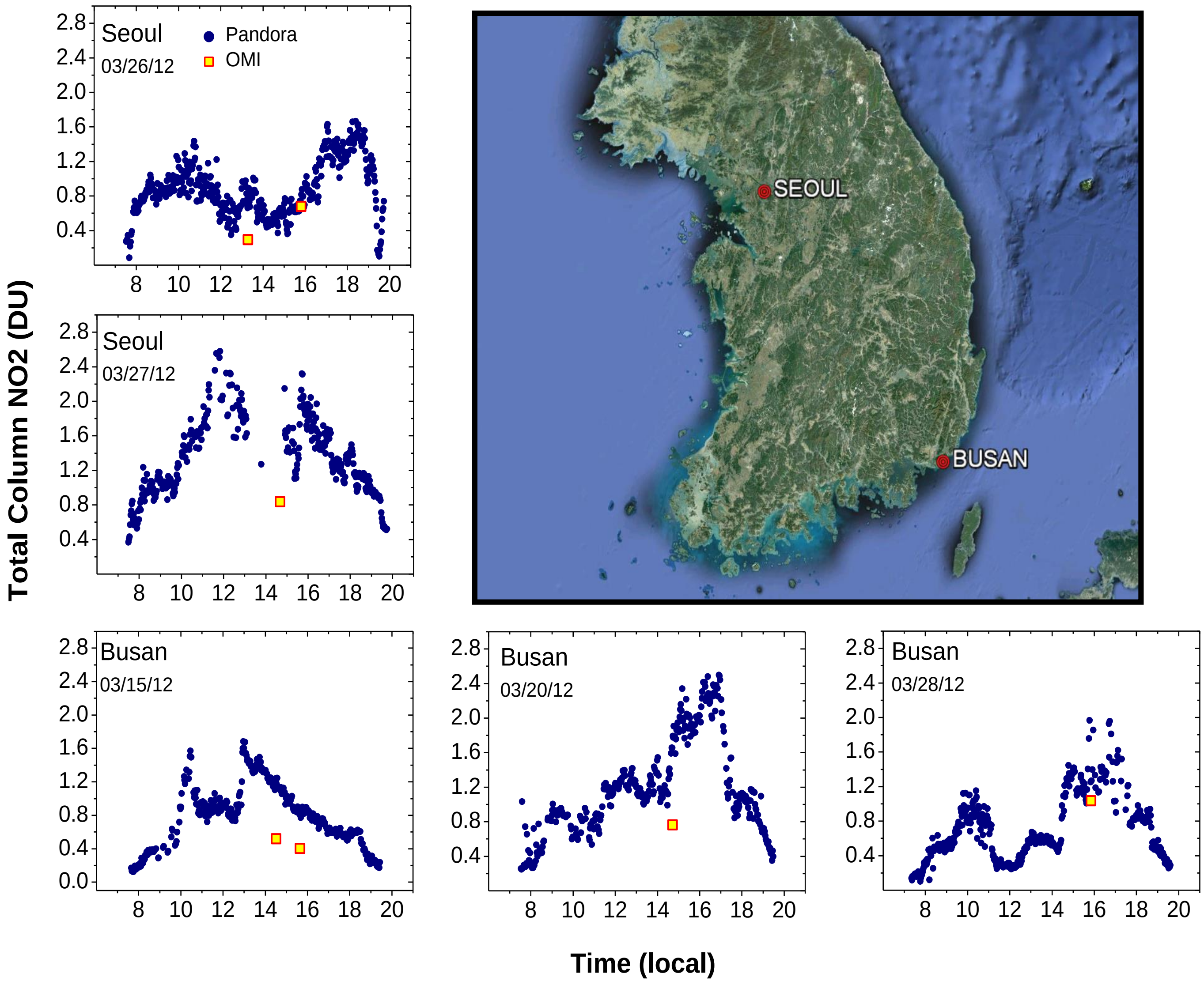


Tzortziou et al 2014, JGR-Oceans, 119, 3834–3854

Atmospheric NO_2 dynamics and impacts on coastal ocean color



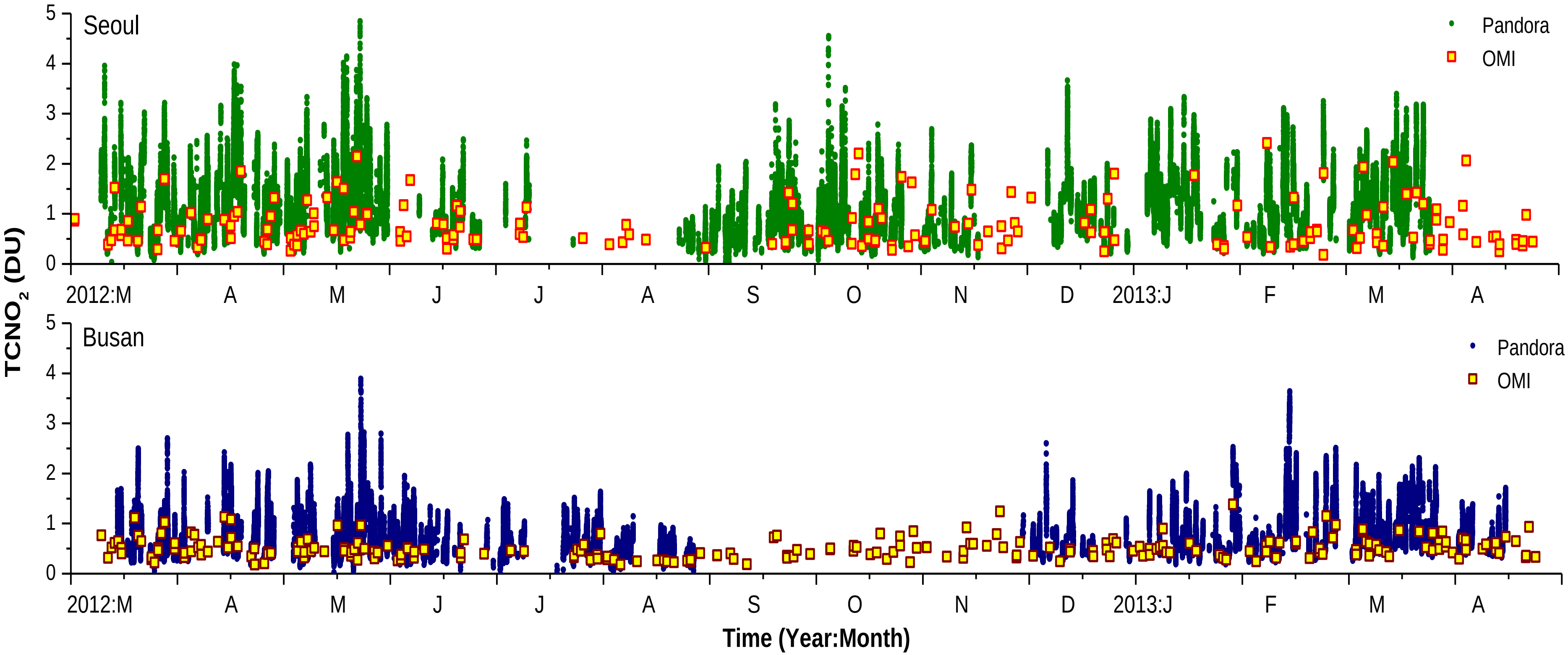
Spatial & temporal variability in $TCNO_2$ – Seoul and Busan in Korea



Tzortziou et al 2014, JGR-Oceans, 119, 3834–3854

Spatial & temporal variability in $TCNO_2$ – Seoul and Busan in Korea (march 2012-April 2013)

With a coarse resolution and an overpass at around 13:30 local time, OMI
→ cannot detect this strong variability in NO_2
→ missing pollution peaks from industrial and rush hour activities.



Tzortziou et al 2014, JGR-Oceans, 119, 3834–3854

What is the impact on ocean color?

Radiative Transfer Code

Ahmad and Fraser (1982) and Mobley (1988; 1994).

→ Both codes have been extensively validated

→ We have **linked** the two codes, so that output from one code is provided as input to the other for a more complete and accurate description of the ocean-atmosphere system.

Hydrollight simulations: *Rrs* spectra

- [Chla]=23 mgm^{-3}
- [TSS] = 20 mgm^{-3}
- $a_{CDOM}(300) = 2.1\ m^{-1}$

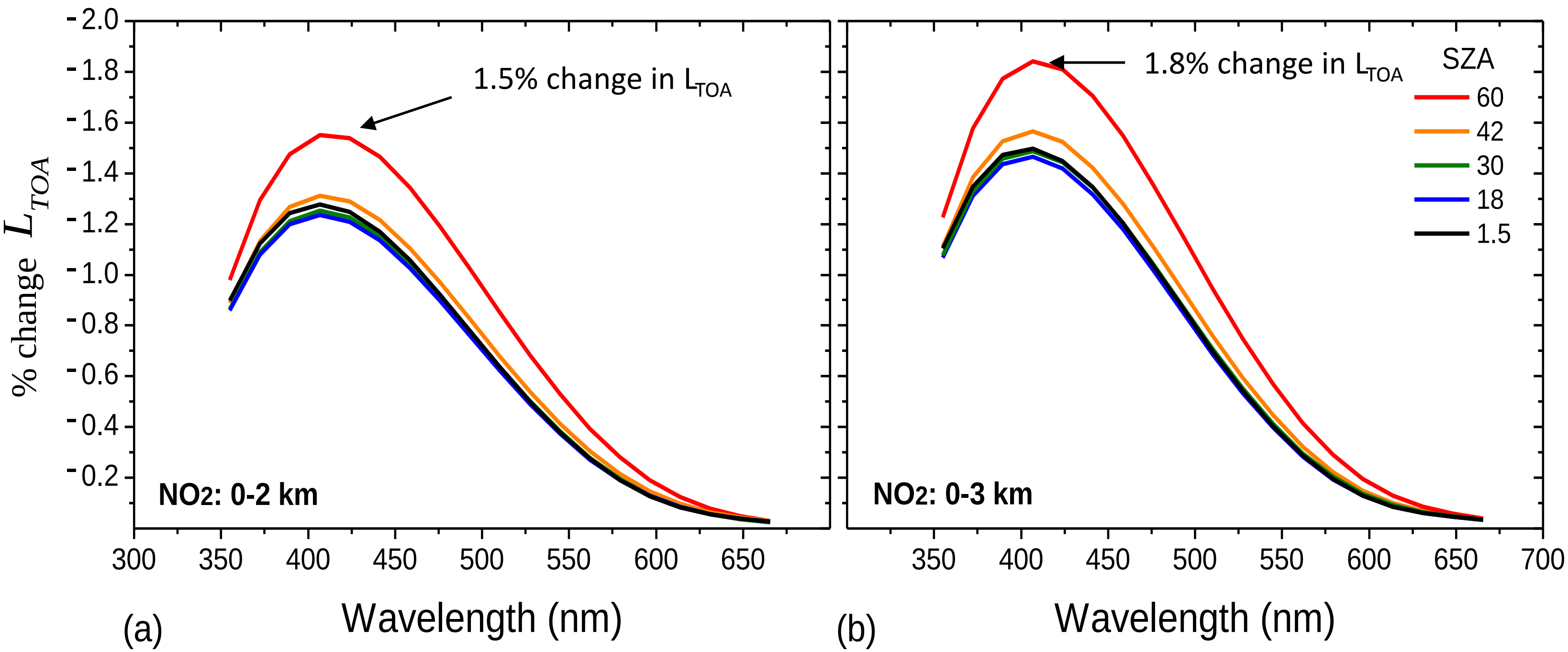
Ahmad-Fraser (AF) code: TOA reflectance, $\rho_{TOA}(\lambda)$

- 300 nm - 3.0 µm
- Includes aerosols and trace gases
- Vandaele et al. (1998) values of NO_2 absorption cross-section
- RT calculations for SZA: 1.5°, 18°, 30°, 42° and 60° , varying azimuth angles depending on geometry, and look angles of 36°, 42° and 48°
- homogeneous NO_2 vertical distribution within the first (i) 2 km and (ii) 3 km from the ground, based on air-quality model simulations (CMAQ).

Tzortziou et al 2014, JGR-Oceans, 119, 3834–3854

Percent change in TOA signal, caused by a change of 1 DU of NO_2

$$\% \text{ change } L_{TOA}(\lambda) = \frac{L_{TOA}(\lambda)_{(\mathrm{NO2}=1\,\mathrm{DU})} - L_{TOA}(\lambda)_{(\mathrm{NO2}=0\,\mathrm{DU})}}{L_{TOA}(\lambda)_{(\mathrm{NO2}=0\,\mathrm{DU})}}$$



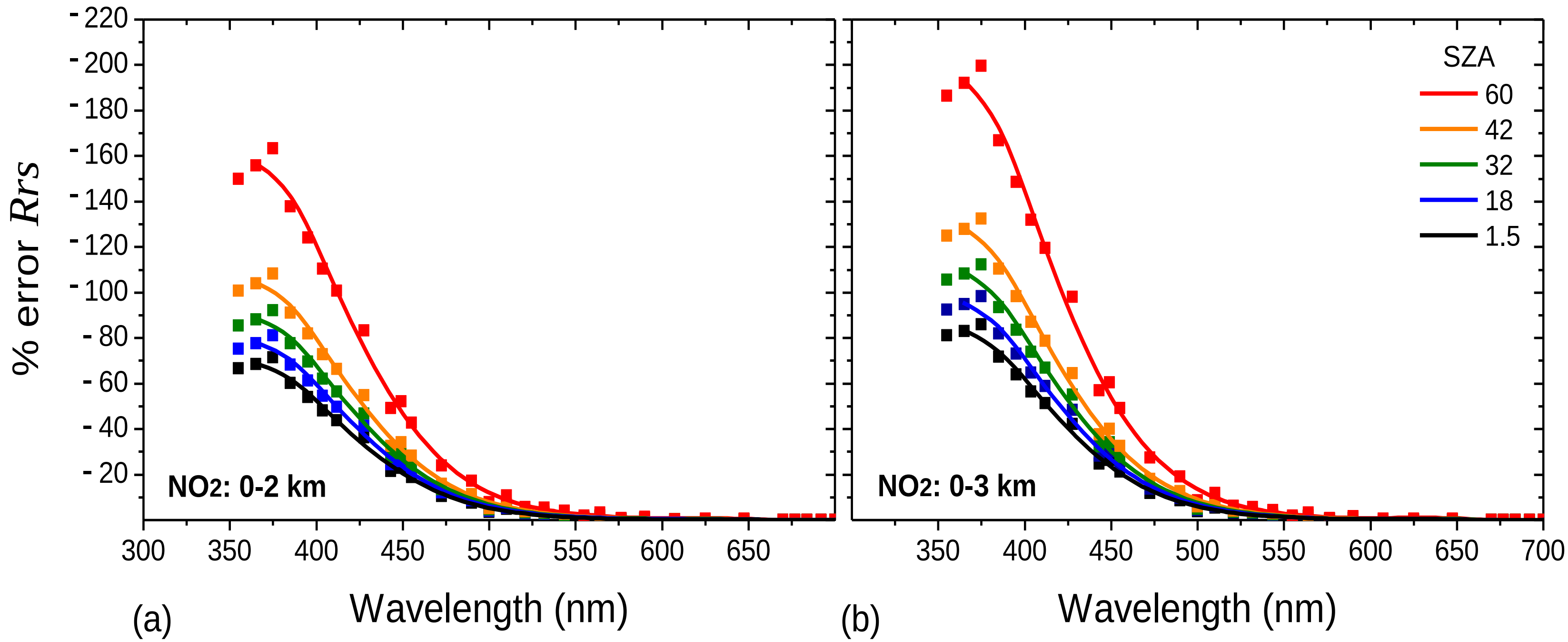
The impact on *L_{TOA}*

- has a strong spectral dependence: **max in 400-420 nm**, due to spectral shape in NO_2 abs. cross sections
- has a SZA dependence: because of the larger slant path with increasing SZA, which results in more scattering and, hence, more absorption
- depends on NO2 vertical distribution, and becomes larger as the NO_2 is distributed at higher altitudes

Percent error in R_{rs} caused by not accounting for 1 DU of atmospheric NO_2

(or, error when a change in TOA is wrongfully attributed to a change in ocean contribution)

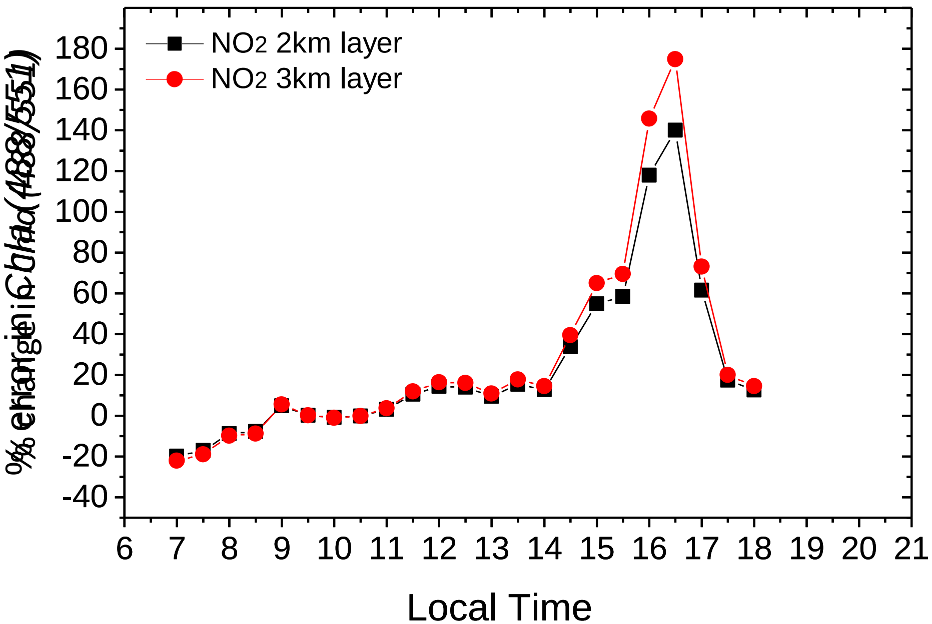
L_w / L_{TOA} =2.5% at 412 nm and SZA=30°

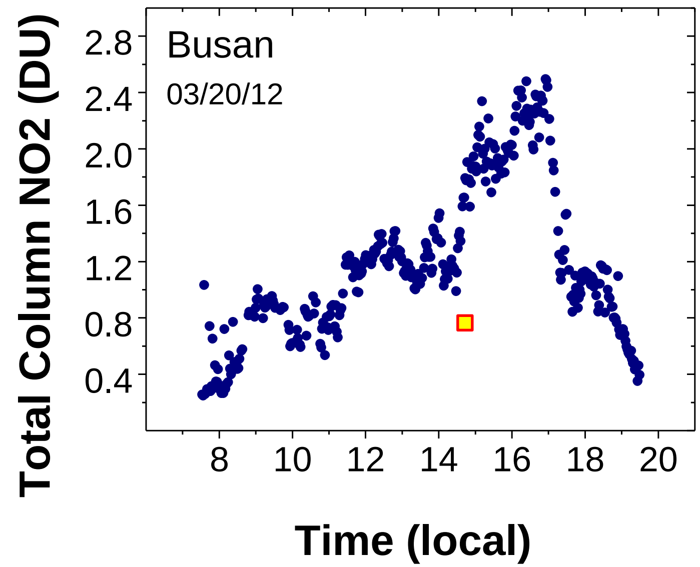


The error in *Rrs*

- has a strong spectral dependence: **max in 350-400 nm**, due to spectral dependence of Lw / L_{TOA}
- has a SZA dependence: because the error in L_{TOA} increases with increasing optical path, and because the relative contribution of Lw to the TOA signal decreases with increasing solar zenith and look angles
- depends on NO_2 vertical distribution, and becomes larger as the NO_2 is distributed at higher altitudes

False variability (%) in retrieved Chla due to unaccounted variability in NO_2 using MODIS OC3M





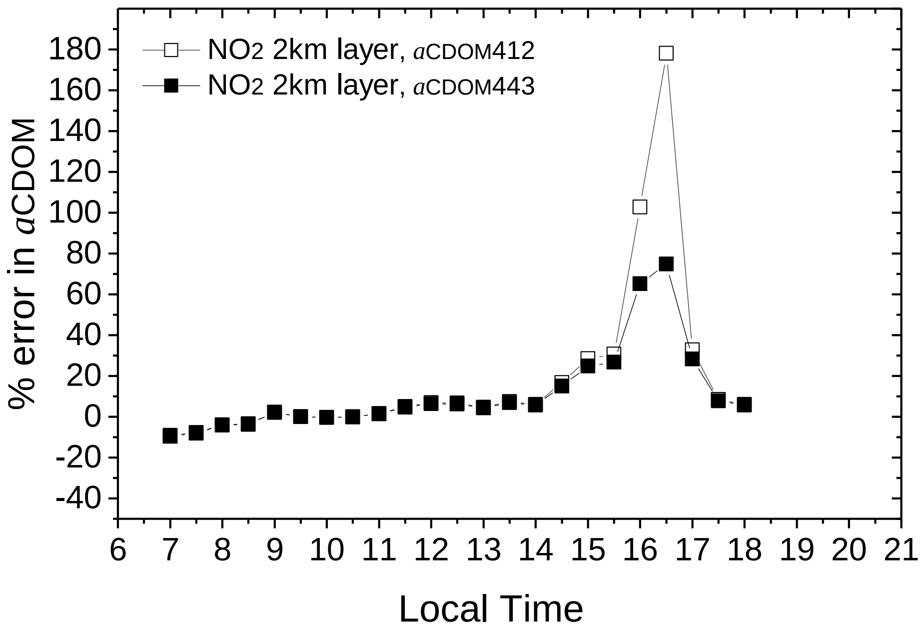
→ **Impact of using the OMI value (0.75 DU) instead of the $TCNO_2$ measured by Pandora (0.4 to 2.4 DU)**

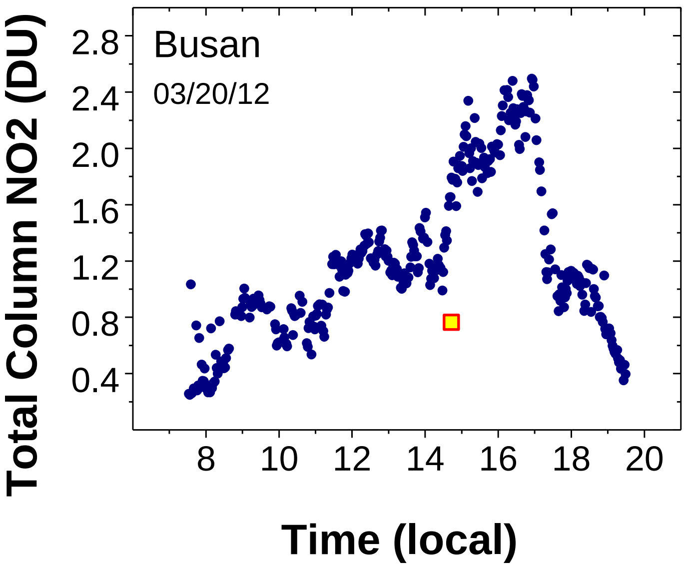
False variability (%) in retrieved CDOM due to unaccounted variability in NO_2

$$a_{CDOM}(\lambda) = \ln\left[\frac{R_{rs}ratio - a}{b}\right] / (-c)$$

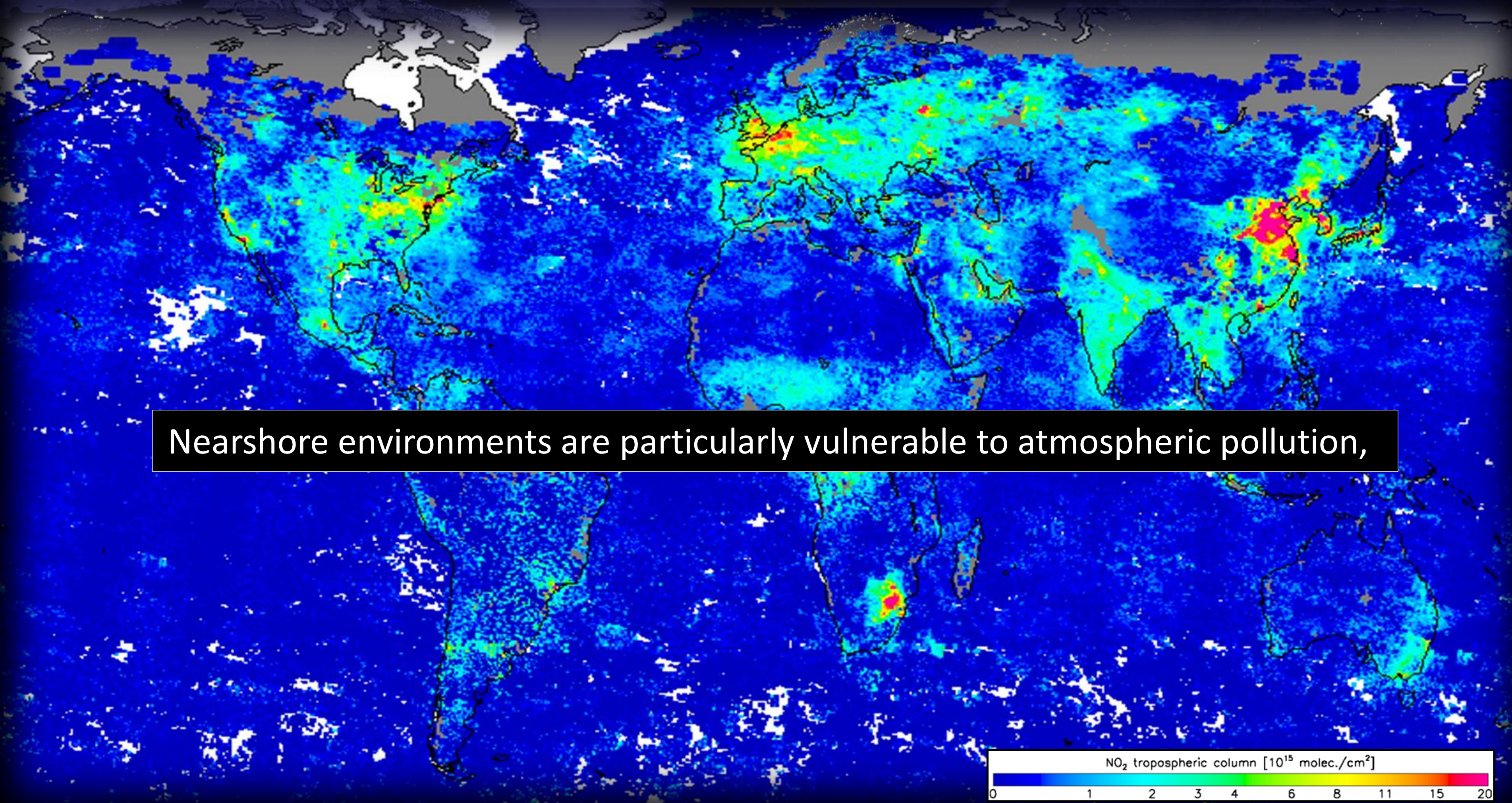
R_{rs} *ratio*: $R_{rs}(490)/R_{rs}(555)$ for SeaWiFS
$R_{rs}(490)/R_{rs}(551)$ for MODIS-Aqua
Mannino et al (2008)

The error in CDOM is spectral dependent: it affects the CDOM ***absorption spectral shape S_{CDOM}***





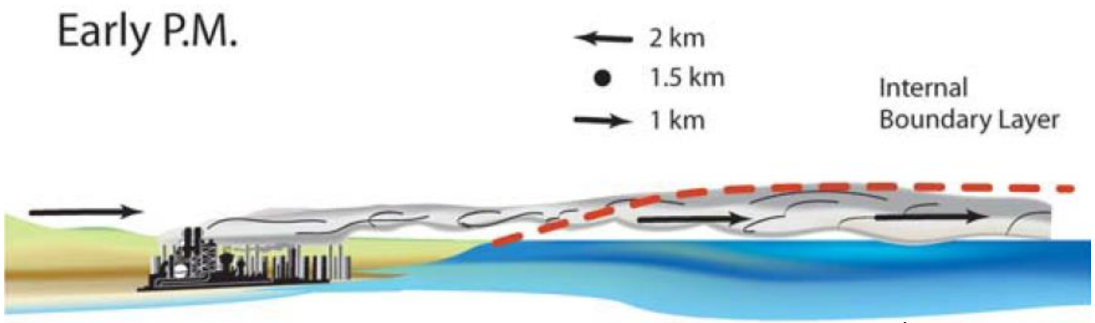
→ **Impact of using the OMI value (0.75 DU) instead of the TCNO$_2$ measured by Pandora (0.4 to 2.4 DU)**



Nearshore environments are particularly vulnerable to atmospheric pollution,

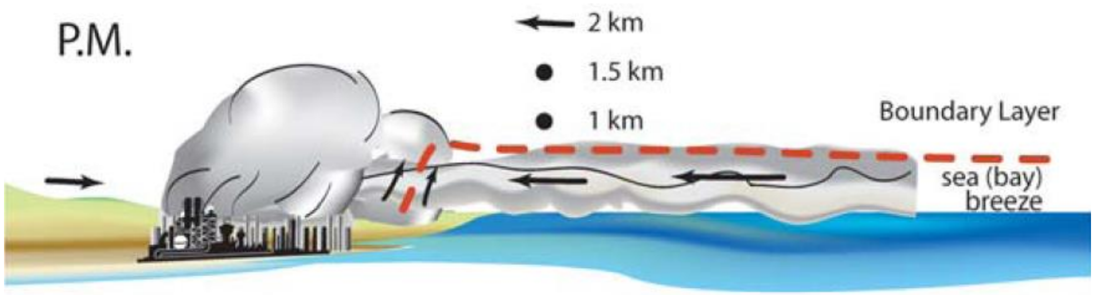
Build-up of air pollution along shorelines during sea/lake/bay- breeze events

Prior to the development of the bay/sea breeze
Offshore winds transport pollutants from urban areas out over the surface waters of the estuary.



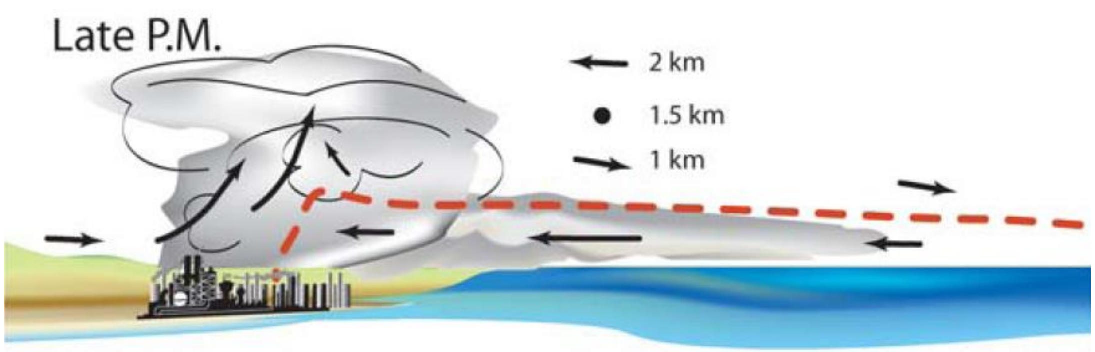
Banta et al., 2005, BAMS

As the bay/sea breeze develops
Winds start changing direction, stagnation develops over the estuary – accumulation of pollutants



Once the bay breeze forms
- Onshore winds transport the high concentrations of surface pollutants towards the coastline.
- Converge with freshly emitted urban pollution
- Maxima in concentrations of pollutants at the land-ocean interface…

Strong, prolonged bay breeze
Produces stronger convergence resulting in pollutants being transported upward, out of the BL to the free troposphere.
Pollutants in the free troposphere:
→ gain a longer lifetime
→ have a larger impact on climate
→ are susceptible to long range transport

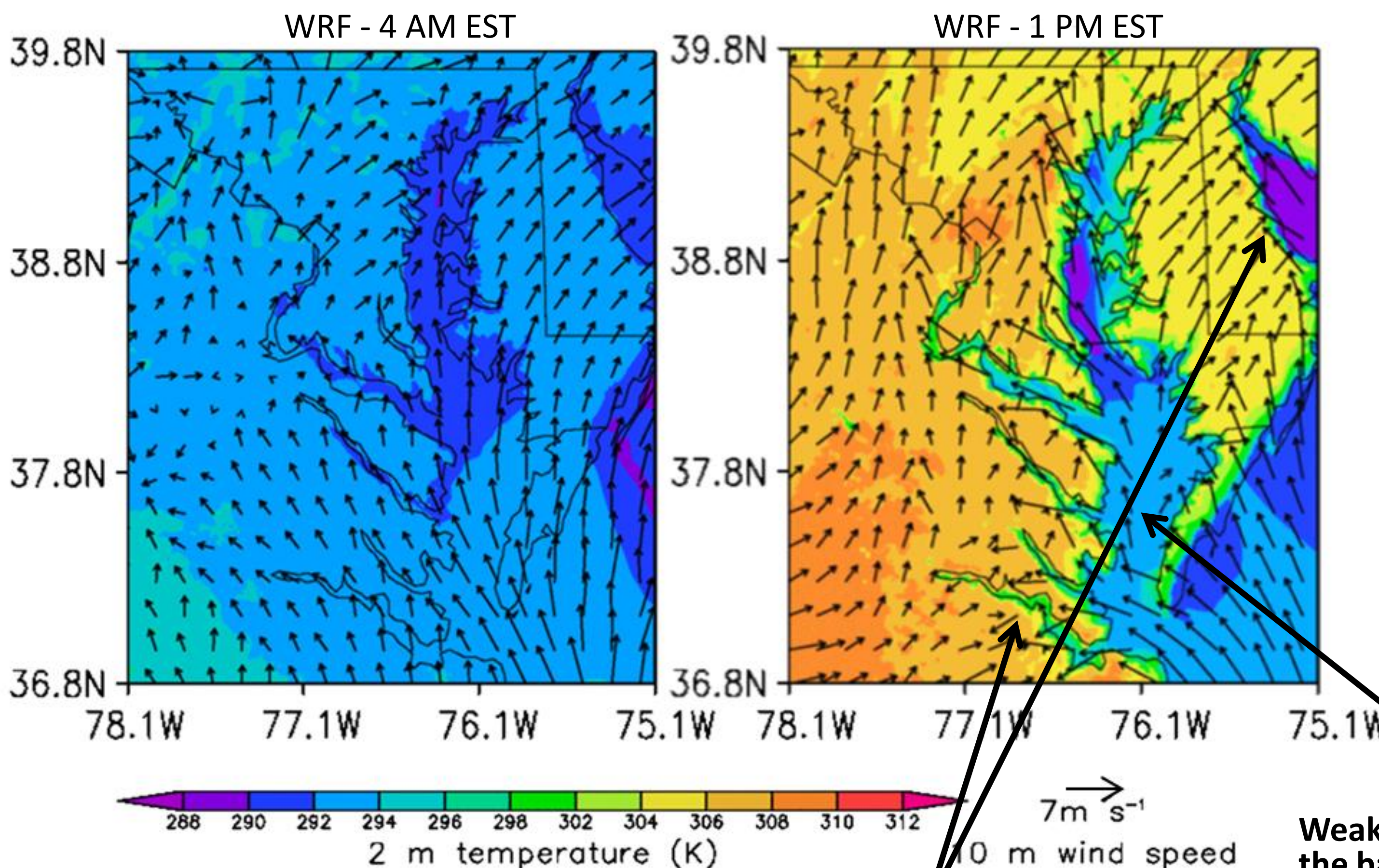


Loughner et al. 2011; Loughner, Tzortziou et al., 2013

Atmospheric pollutants accumulation at the land-water interface

2 July 2011 - DISCOVER-AQ and CBODAQ campaigns over the Chesapeake Bay

WRF (Weather Research and Forecasting) simulations



Bay Breeze develops, winds change direction

Weak winds over the bay reveal areas of stagnation due to winds changing direction associated with the bay breeze.

Atmospheric pollutants accumulation at the land-water interface

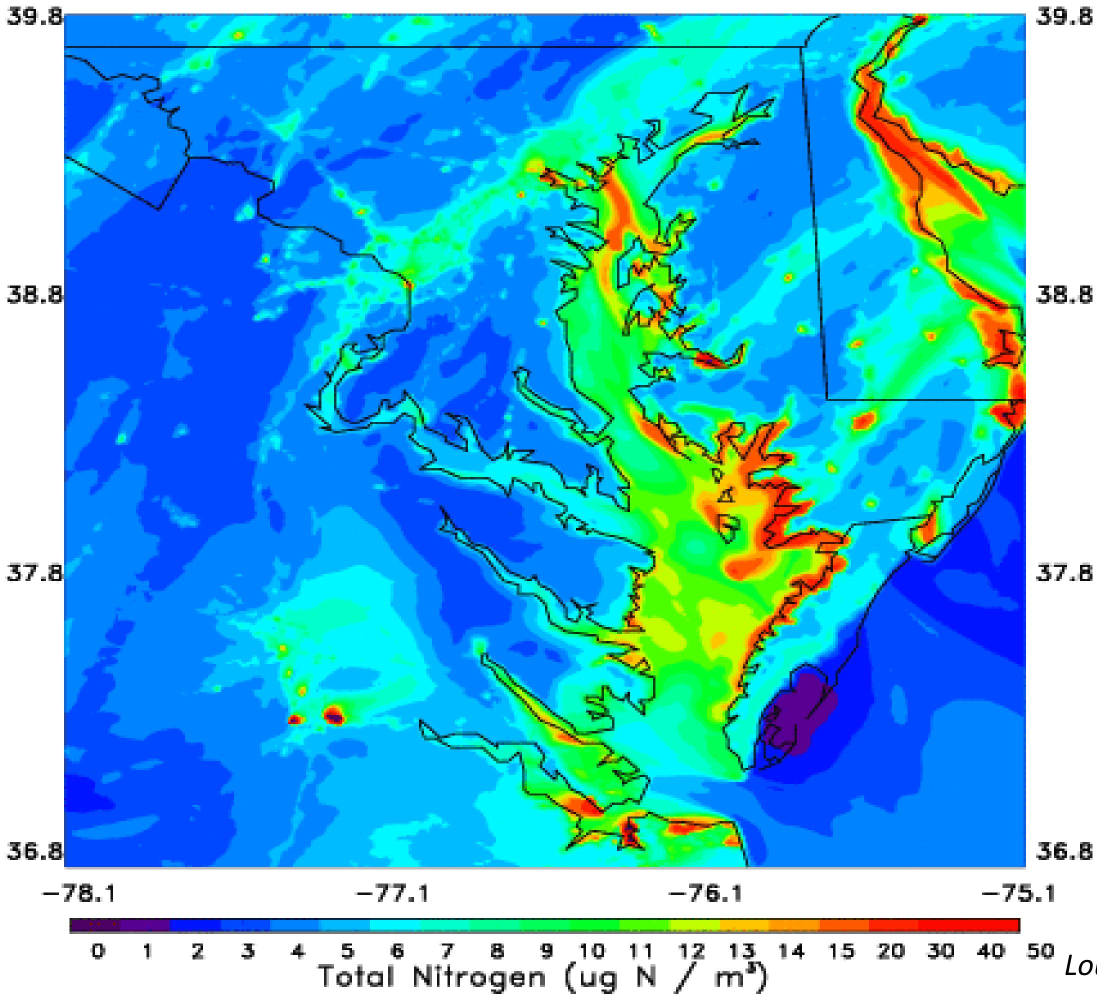
2 July 2011 - DISCOVER-AQ and CBODAQ campaigns over the Chesapeake Bay

CMAQ (Community Multi-scale Air Quality) simulations run at high (1.3 km) horizontal spatial resolution

Stagnation and low deposition rates result in pollutant buildup over the estuarine waters, and along the shorelines.

Total atmospheric nitrogen near the surface

CMAQ - 1:00 PM EST



Loughner and Tzortziou, In Prep

Summary

❖ To account for the known strong NO_2 variability in coastal ocean color retrievals, requires measurements of NO_2 **at a spatial & temporal resolution relevant to the satellite ocean color observations**.

❖ NO_2 observations from coarser resolution atmospheric sensors (e.g., OMI 12km x 24 km at nadir) **do not capture the strong temporal and spatial variability of NO_2 in coastal waters**

❖ **0.7 DU** unaccounted variability in NO_2, resulted in an **error in coastal water Rrs(412) as large as 40% at low SZAs (< 30°), while it gets as large as 70-80% for large SZAs.**

❖ The error in Rrs gets larger:
- at **larger NO_2 amounts** (e.g., Busan: 2 DU change in NO_2: > 150% error in Chla and CDOM abs coeffs)
- at **shorter wavelengths** (350-400 nm)
- at **larger solar zenith and look angles**
- as the NO_2 is distributed **at higher altitudes**

❖ Accurate atmospheric correction for NO_2 requires information on NO_2 vertical distribution

❖ Meteorological processes such as bay/sea/lake breezes often result in **accumulation of atmospheric pollution over estuarine and coastal waters**, as well as transport of pollutants out of the BL in the free troposphere and **over long distances and over the coastal ocean, further away from emission sources**

❖ **More shipboard measurements** are needed over the ocean to understand NO_2 dynamics, vertical distribution, dispersion, and gradients in coastal environments