GOME-2 HCHO Air Mass Factors
– Algorithm Development

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Acknowledgments

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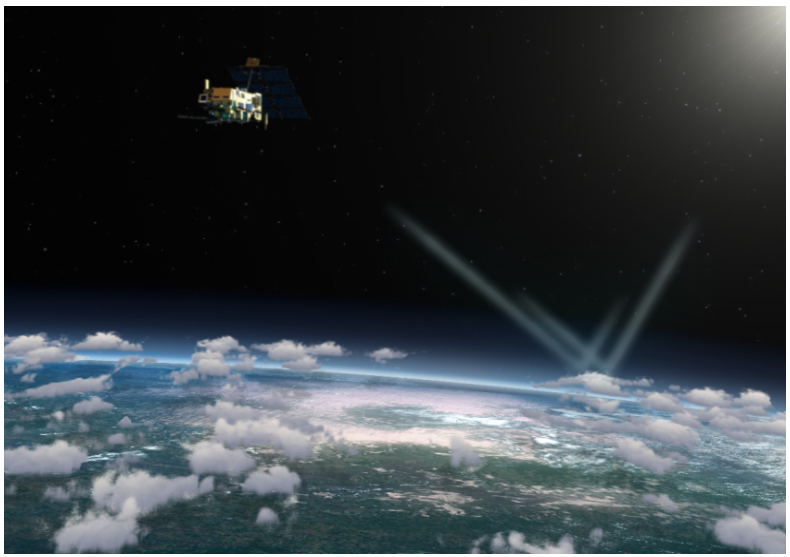
  BIRA, Belgium.
- Gijsbert Tilstra
  KMNI, Netherlands.

Our focus:

GOME-2 (on Met-Op A)



- Spectral range: 240–790 nm
- Spectral resolution: 0.24–0.5 nm
- Footprint: 80×40 km^2
- Sun-synchronous orbit
- Local equator crossing time 09:30

Formaldehyde (HCHO)

- Main source: oxidation of nmVOCs
- VOC sources:

  Biogenic: $\sim$1150 Tg C yr^{-1}

  Anthropogenic: $\sim$150 Tg C yr^{-1}

  Pyrogenic: $\sim$50 Tg C yr^{-1}
- HCHO is short-lived (hours)
- Useful proxy species for inferring surface emissions (e.g, isoprene)

Satellite Air Mass Factors

- Definition: AMF = slant column density / vertical column density
- AMF converts retrieved trace gas slant columns to geophysical quantity
- Accurate AMFs are important to improve retrieved measurements
- A 'good' estimate of AMF errors is needed to properly calculate the **overall retrieval uncertainty**, which is important for:
  - Weighting observations when gridding/averaging
  - Measurement validation & model comparisons
  - Determining errors of inferred quantities (e.g., surface emissions)
- Palmer et al. [2001] developed a widely used method for calculating AMFs:

$$AMF(\lambda) = AMF_G \int_0^{TOA} S(\sigma)\, w(\lambda, \sigma)\, d\sigma$$

  - $w(\lambda, \sigma)$ are scattering weights that represent the sensitivity of the backscattered radiance to the absorber abundance at each altitude
  - $S(\sigma)$ is a normalised shape factor that describes the trace gas vertical distribution
- Final AMF is sum of reflectivity weighted clear and cloudy pixel sub-scene:

$$AMF(\lambda) = \frac{AMF_{clr}\, R_{clr}\, (1-f) + AMF_{cld}\, R_{cld}\, f}{R_{clr}\, (1-f) + R_{cld}\, f}$$

GOME-2 HCHO vertical column retrieval

Spectral Fitting

- See Hewson et al., AMT, 2013.
- Two stage fitting (BrO pre-fit)

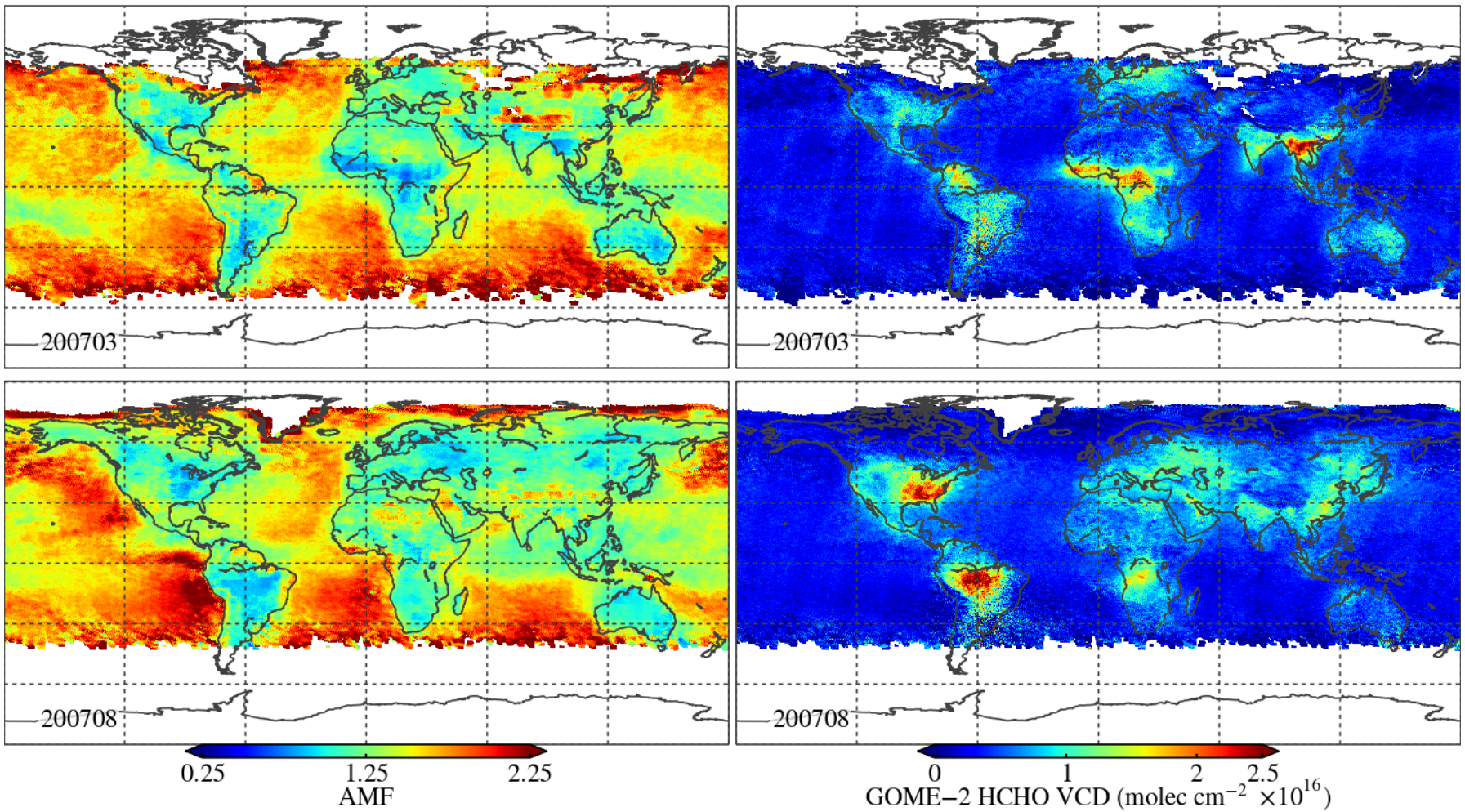
Parameter	Settings
Fit window	BrO 328.5 – 359 nm [Theys, 2010] HCHO 328.5 – 346 nm [De Smedt, 2011]
Polynomial	5^{th} order
Cross sections	BrO (223 K) [Fleischmann et al., 2004] HCHO (298 K) [Meller & Moortgat, 2000] NO_2 (220 K) [Vandaele et al. 1998] O_3 (228 and 243 K) [Malicet et al., 1995] I_0 corrected to 0.8×10^{19}
Linear offset	1^{st} order
Ring	Vountas et al. [1998]
Undersampling	Chance et al. [2005]
Scan correction	Eta & zeta polarisation correction [EUMETSAT 2011]
Slit function	Siddans et al. [2006]
Solar reference	GOME-2 daily solar mean reference
I_0 calibration	Caspar et al. [1997]

AMF

- See Hewson et al., AMTD, 2015.
- Use LIDORT RT code
- Calculate AMF at 340 nm
- Calculate AMF for each scene
  No look-up table
- Aerosol types: black carbon, organic carbon, dust, sulphate, sea salt

	Baseline AMF algorithm
CTM	GEOS-Chem global $4^\circ\times5^\circ$ grid
A Priori Profiles	Daily profiles (HCHO & AOD) - selected using centre coordinates
Surface Pressure	GEOS-Chem ($4^\circ\times5^\circ$)
Surface Albedo	TOMS monthly climatology - Herman & Celarier [1997] - regridded to $4^\circ\times5^\circ$ ($\lambda\sim360$ nm)
Surface Elevation	n/a
LIDORT cross-sections	Fixed OMI cross section
LIDORT O_3 profile	U.S. Standard atmosphere
Cloud Algorithm	FRESCO+

Baseline AMFs and HCHO vertical columns

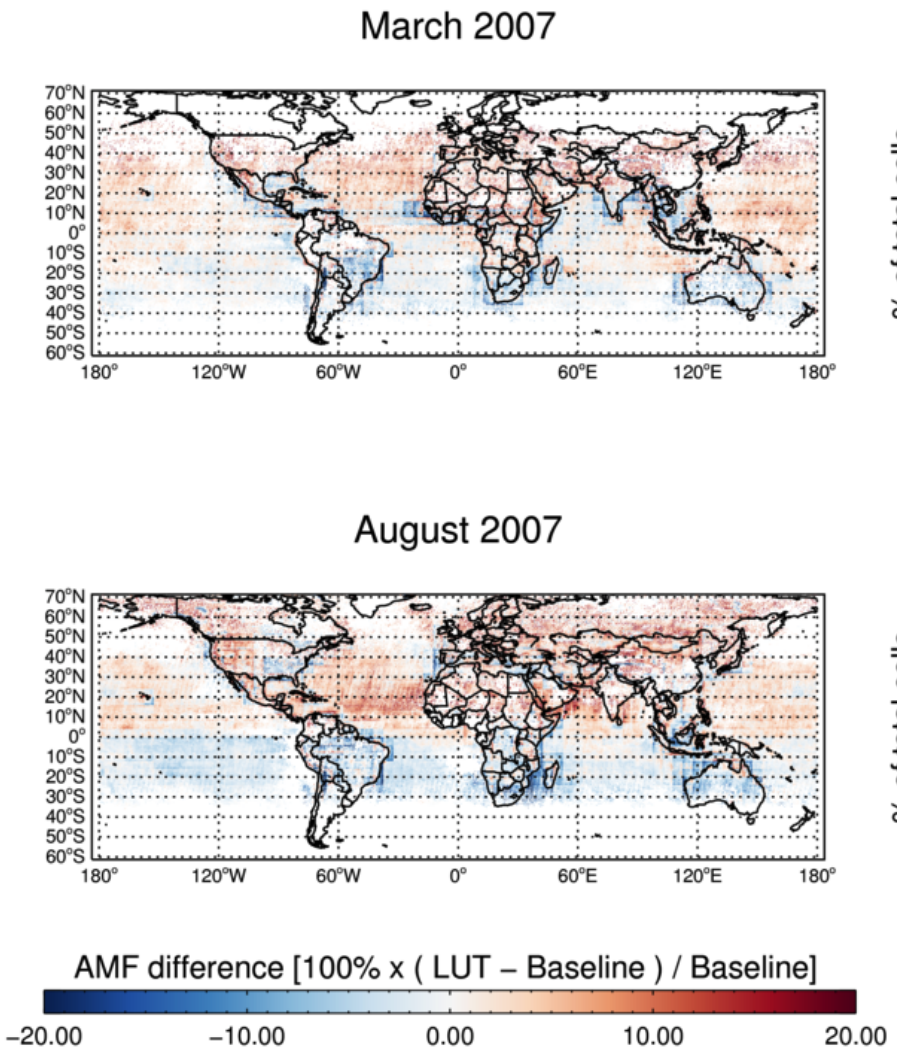


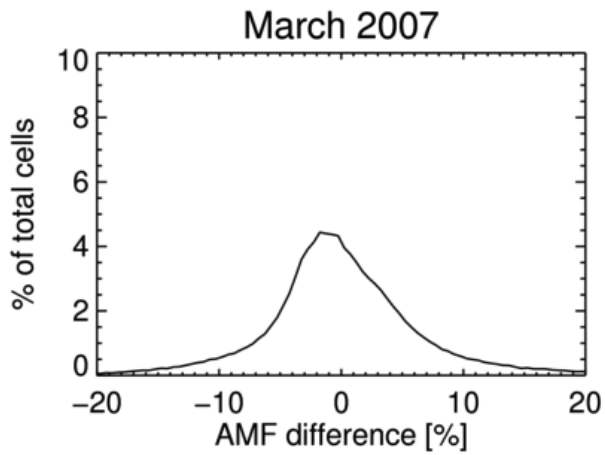
- Focus on contrasting months: March and August of 2007
- *Everything seems in the right place!*

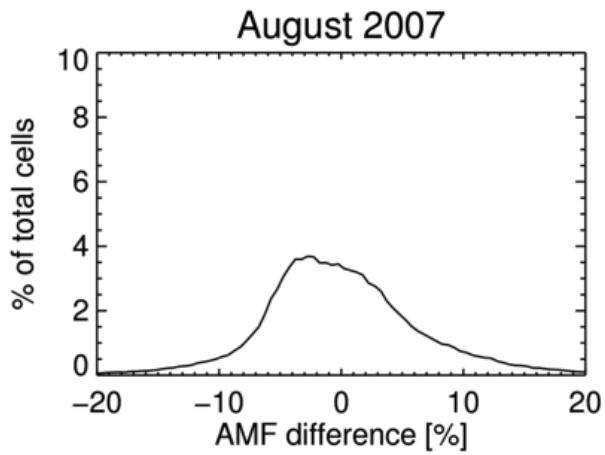
Updates applied

- Assessment of different GEOS-Chem chemistry transport model grid resolutions
  - Coarse: Global $4^\circ \times 5^\circ$ simulation
  - Medium: Global $2^\circ \times 2.5^\circ$ simulation
  - 'High': Regional $0.5^\circ \times 0.667^\circ$ nested (one-way) simulation
- Area-weighting of a priori profiles to match the satellite footprint
- Application of the Zhou et al. [2009] terrain correction for surface pressure
  - Use high resolution surface topography data to adjust coarse surface pressure
- Upgrade of surface reflectance to new GOME-2 climatology
- HCHO and O_3 absorption cross sections within LIDORT changed to match those in retrieval and adjusted to account for change of GOME-2's slit function over time and also for temperature effects
- The US Standard O_3 profile within LIDORT is replaced with TOMS v8 climatology and scaled with coincident GOME-2 total column observations

AMFs from look-up tables

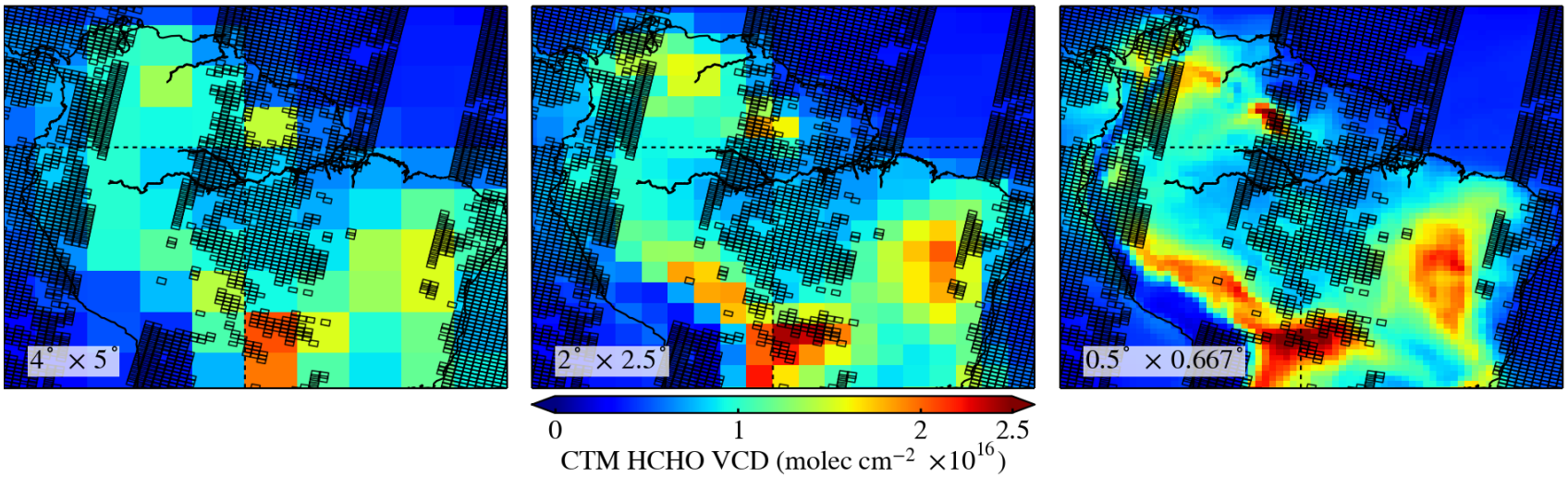


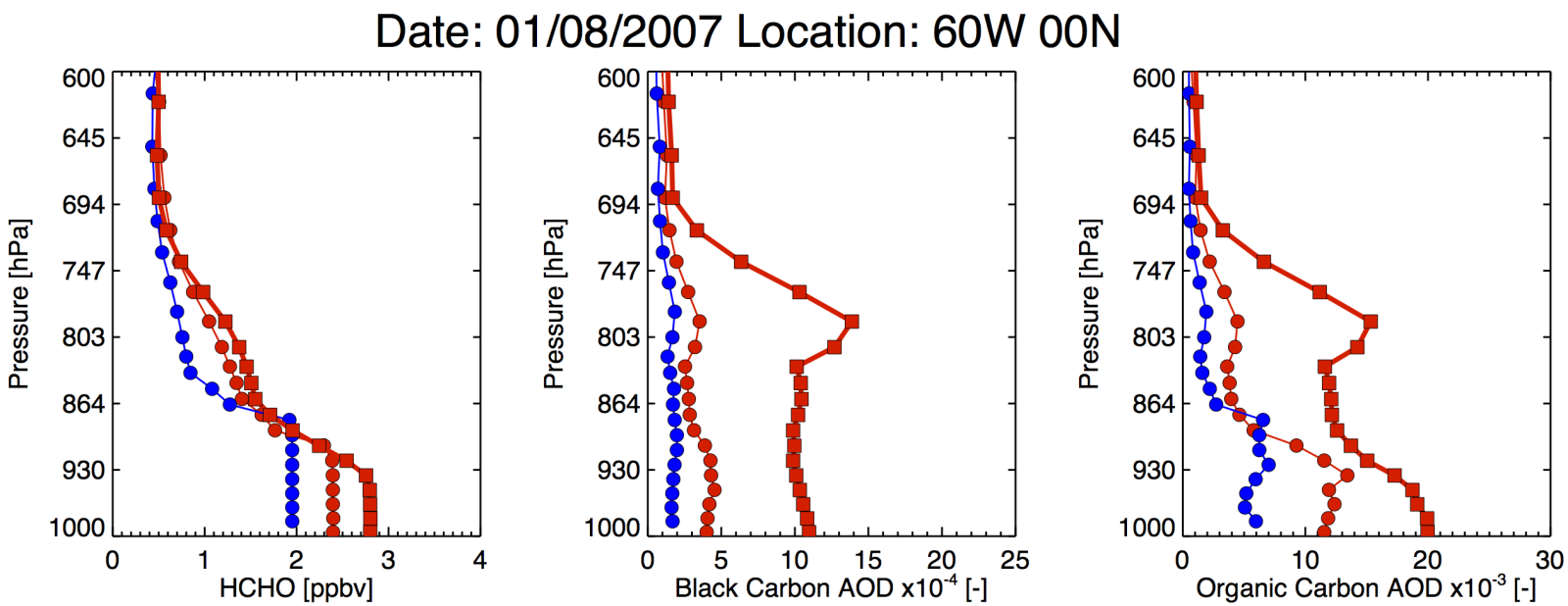




- Compare baseline AMFs to previous look-up table (LUT) approach
- AMF LUT based on monthly mean GEOS-Chem profiles from $4^\circ \times 5^\circ$ simulation

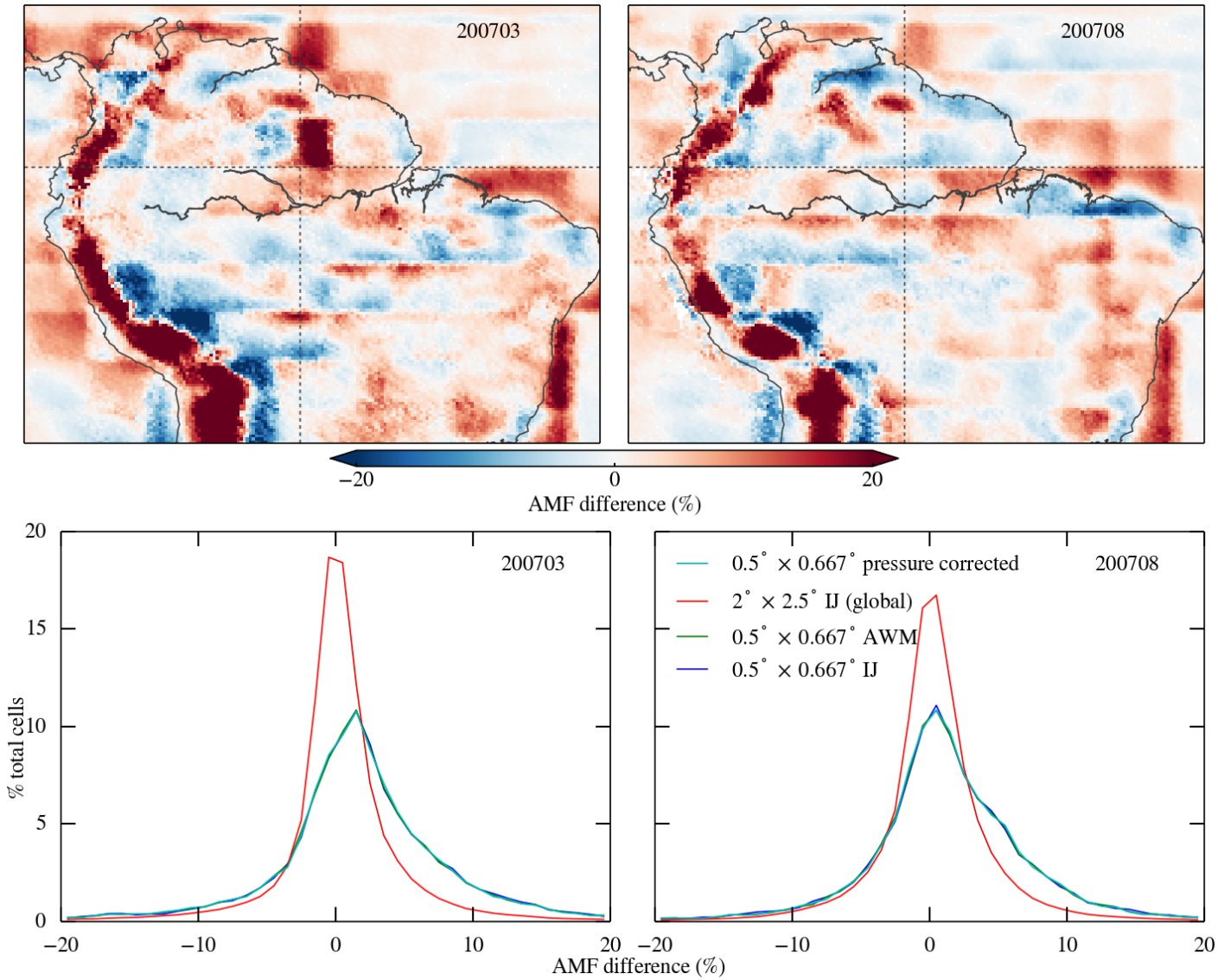
Importance of CTM resolution





Blue dots = Amazon nested simulation; red dots = $4^{\circ} \times 5^{\circ}$ daily profile; red squares = $4^{\circ} \times 5^{\circ}$ monthly mean profile

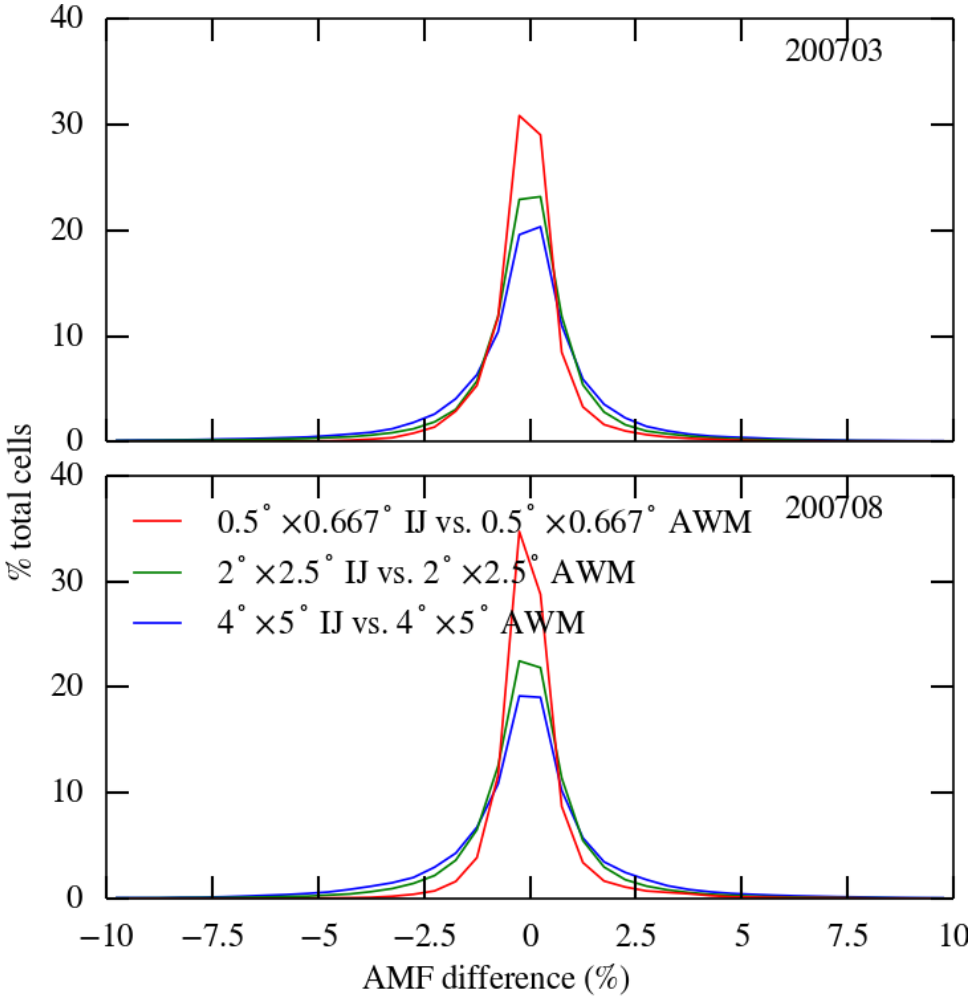
Impact of CTM resolution



Difference = 100% × (Amazon - Baseline / Baseline)

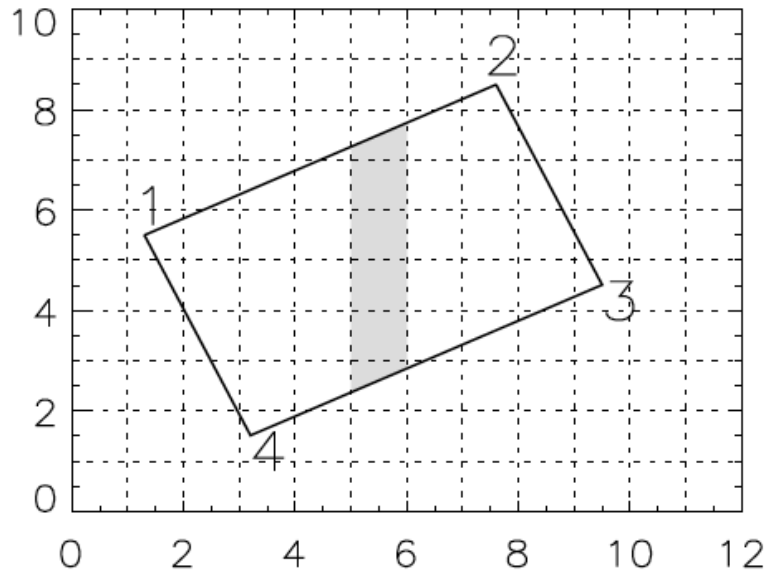
AMF differences greater at higher resolution simulations

Area weighting of model profiles



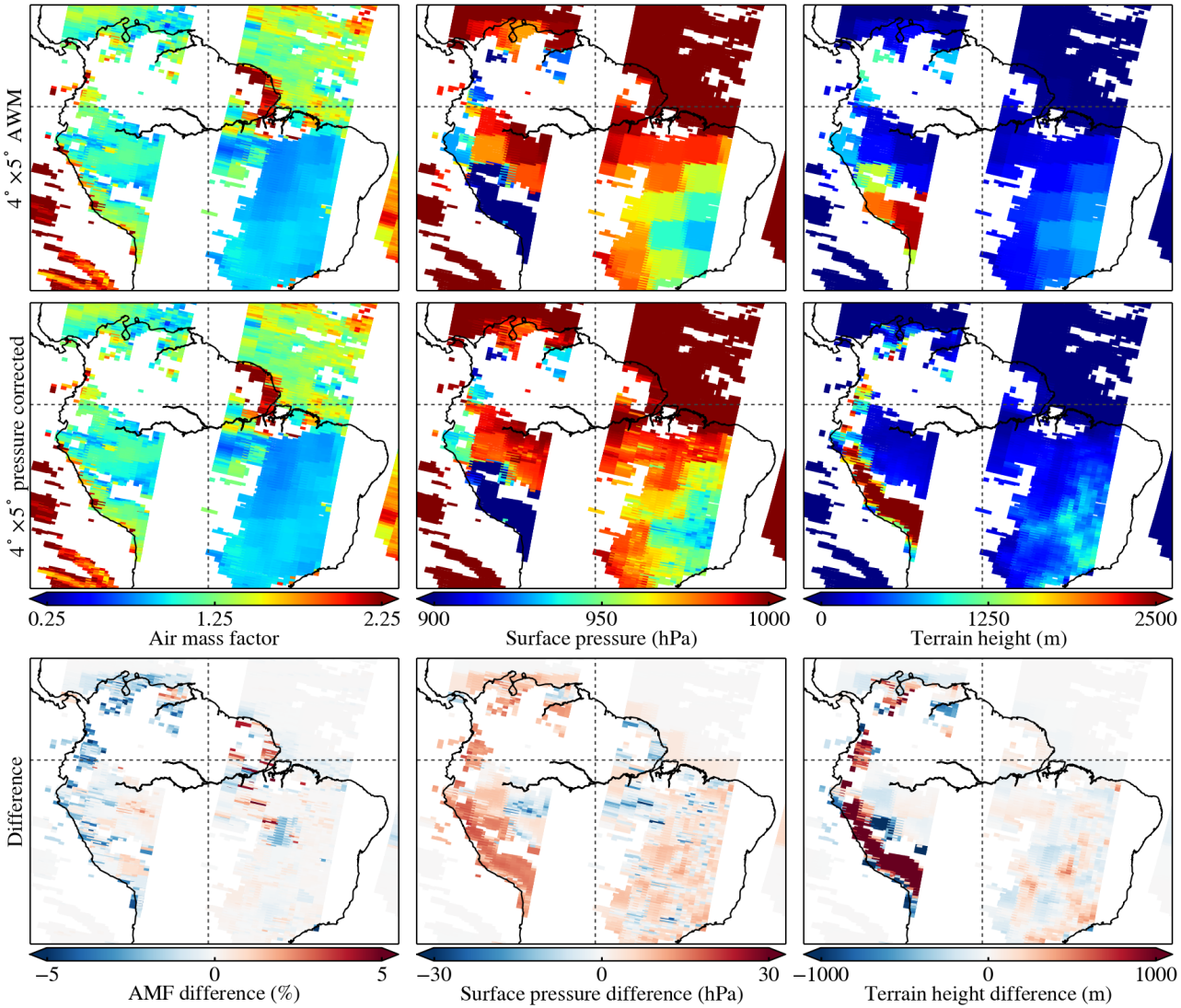
AW of profiles has small effect

CTM spatial resolution more important



- AW mean surface pressure calculated and used to construct common pressure profile
- All profiles interpolated onto pressure profile before AW applied
- Total AOD is conserved by rescaling interpolated profiles

Surface Pressure Correction

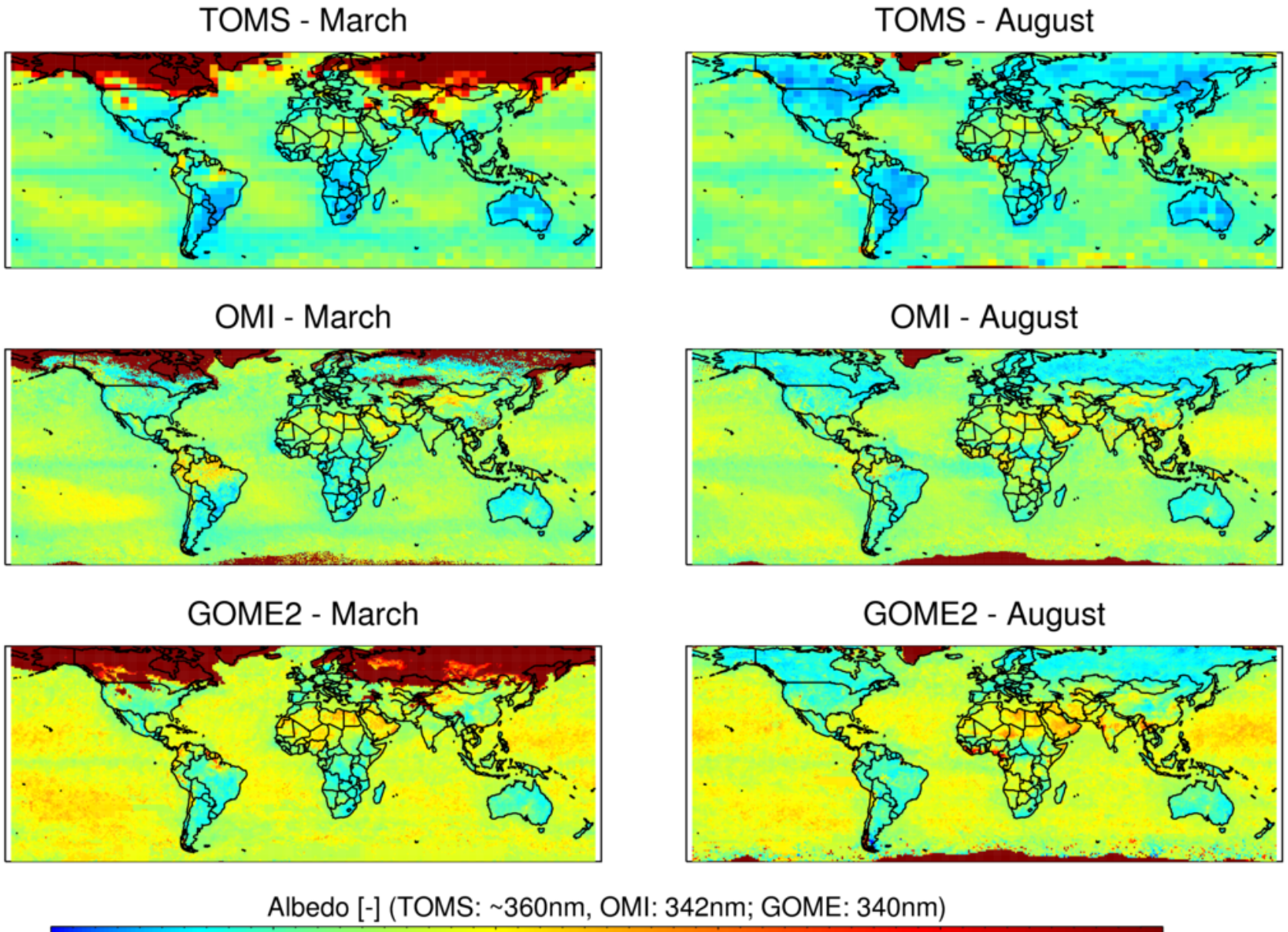


Method:

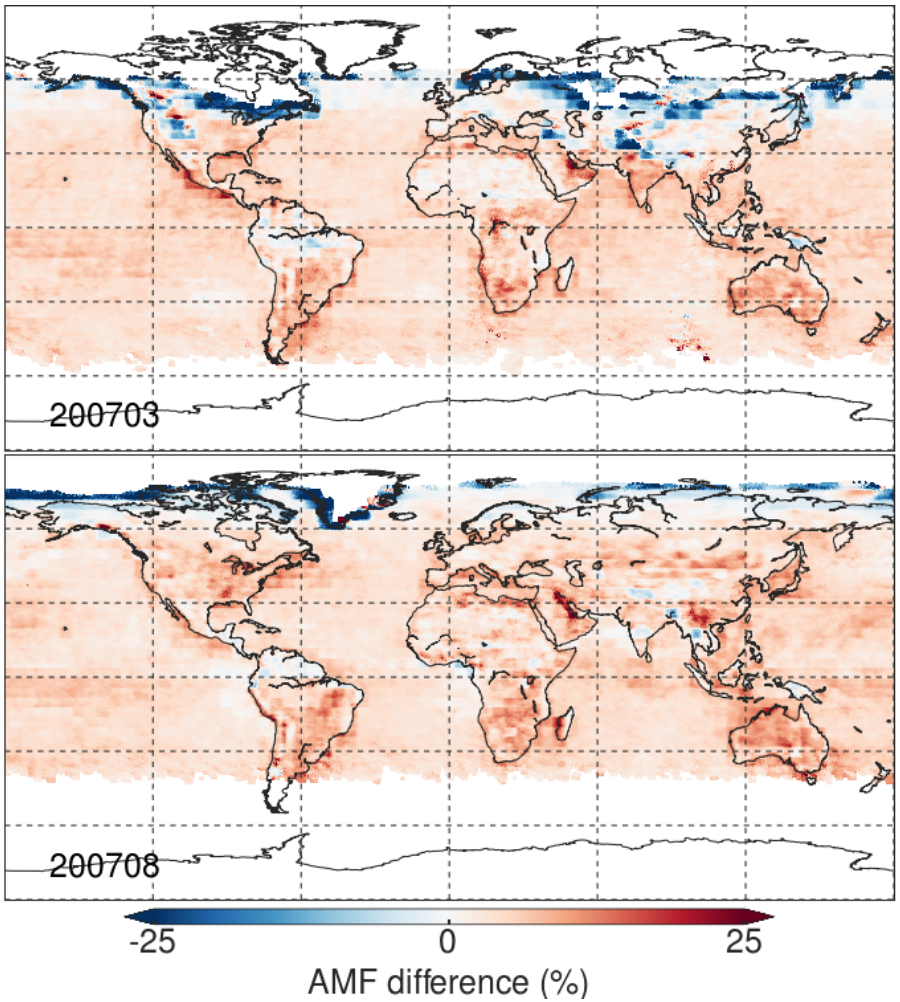
- Utilise GMTED2010 data has a resolution of $0.0083° \times 0.0083°$
- Adjust the area weighted mean surface pressure using GMTED2010 surface topography via Zhou et al. [2009] method
- Construct new pressure profile
- Area weighted model profiles interpolated on to new vertical pressure grid

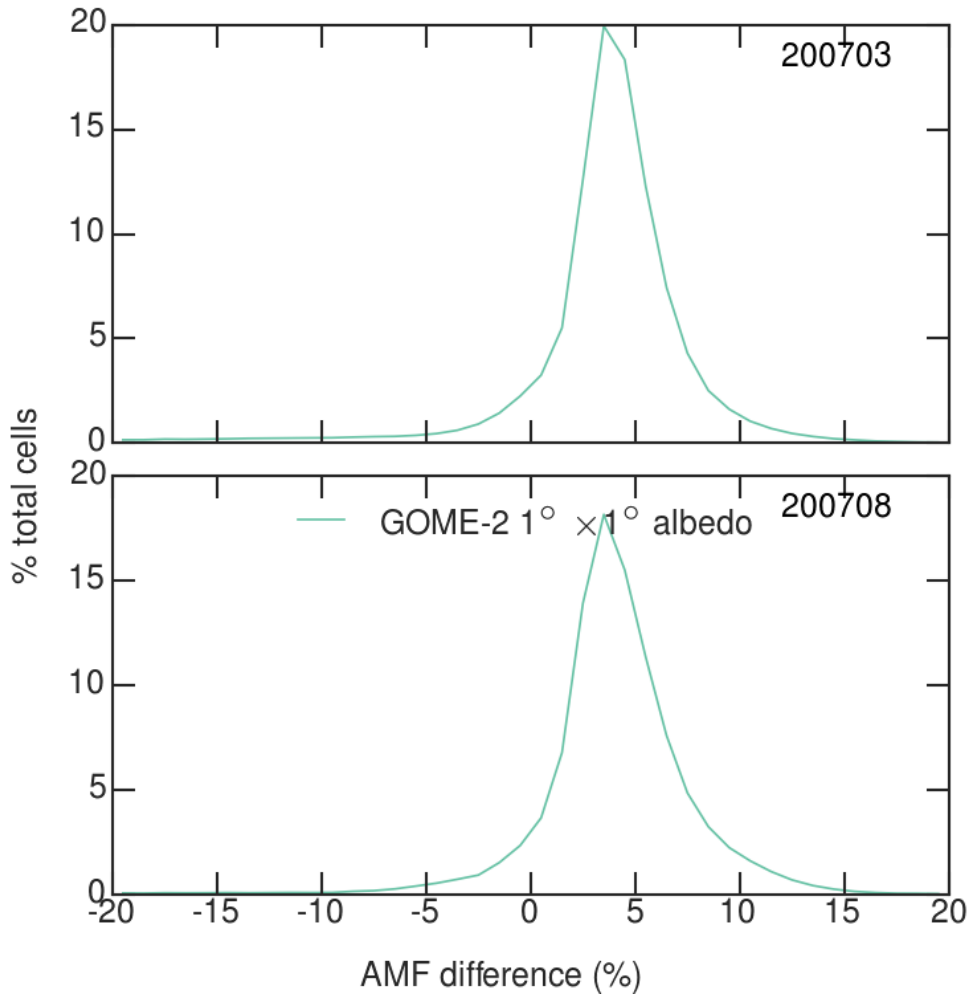
- Over **Amazon**, impact of correction on AW $4° \times 5°$ profiles is **small** $\pm 5\%$
- Impact on AW profiles from GEOS-Chem $0.5° \times 0.667°$ simulation **is even smaller**

Importance of Surface Reflectance



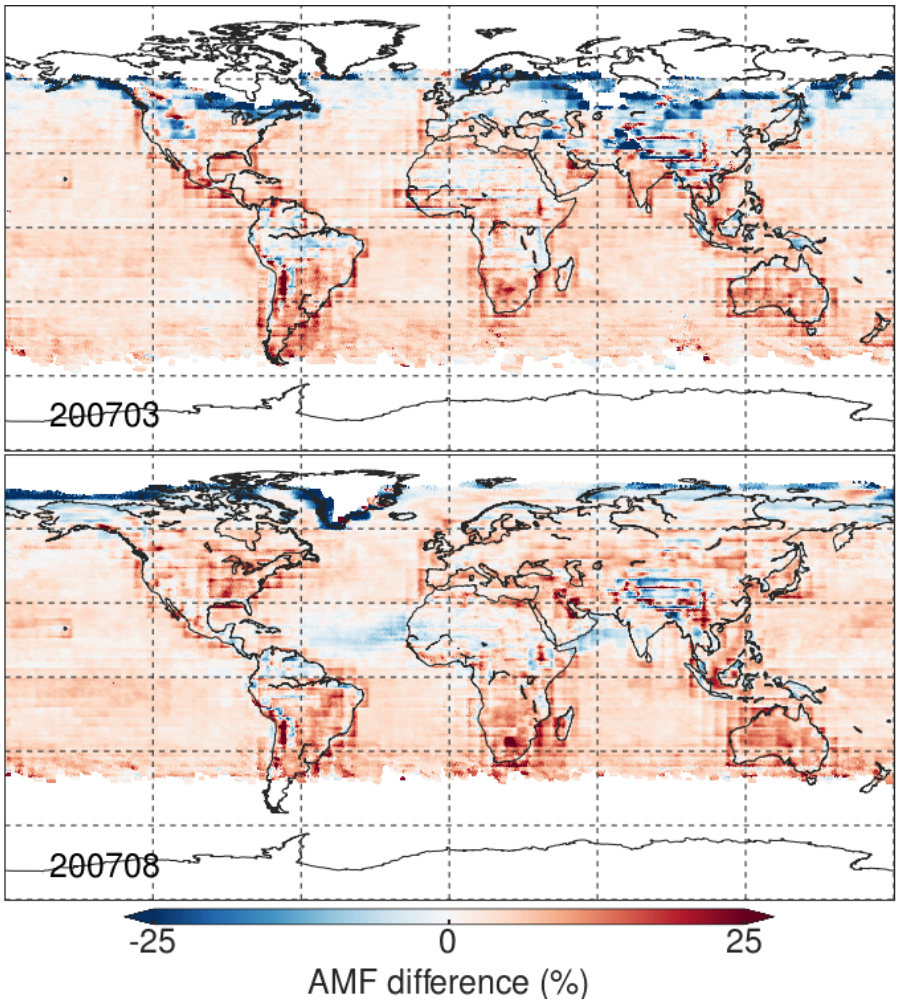
Impact of Surface Reflectance

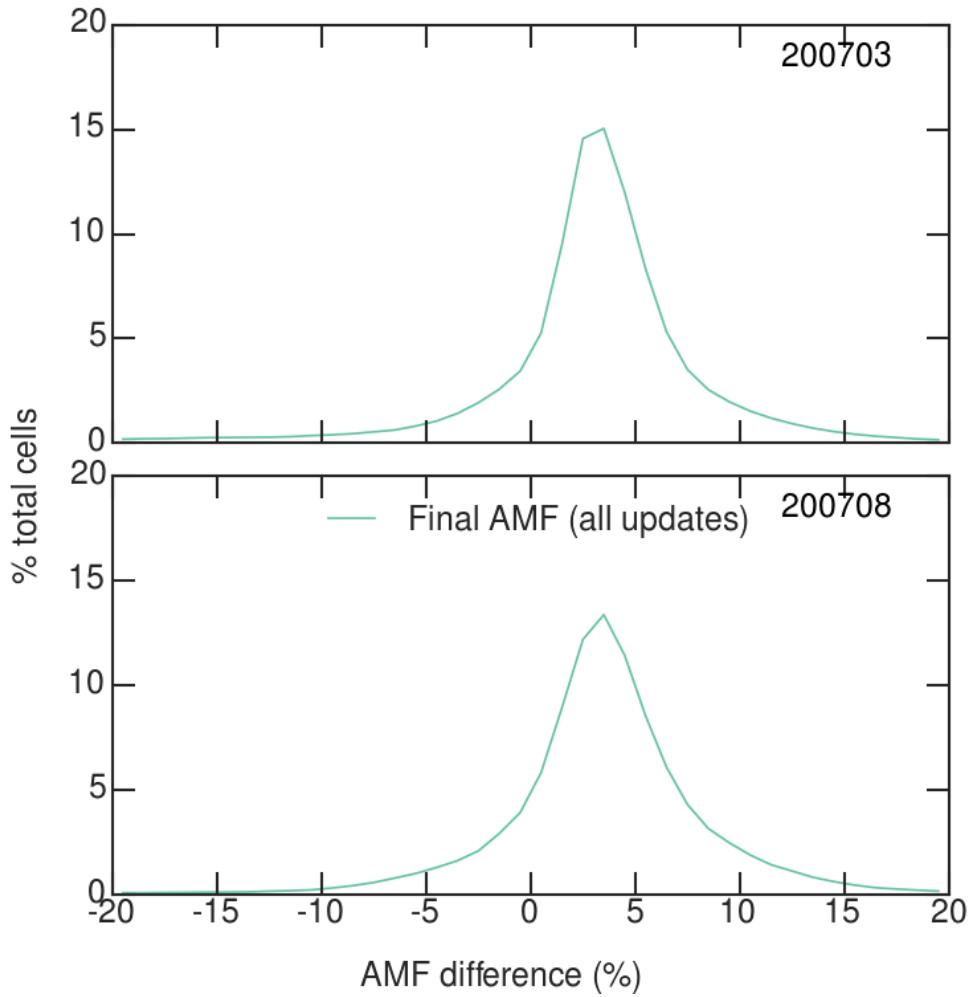




- Use of TOMS reflectance is mainly historical (GEOS-Chem heritage)
- Now implement GOME-2 mode LER data at 340 nm (AW, time interpolated)
- Between 80–90% of locations have AMF increased by 0–20% (mean 4%)

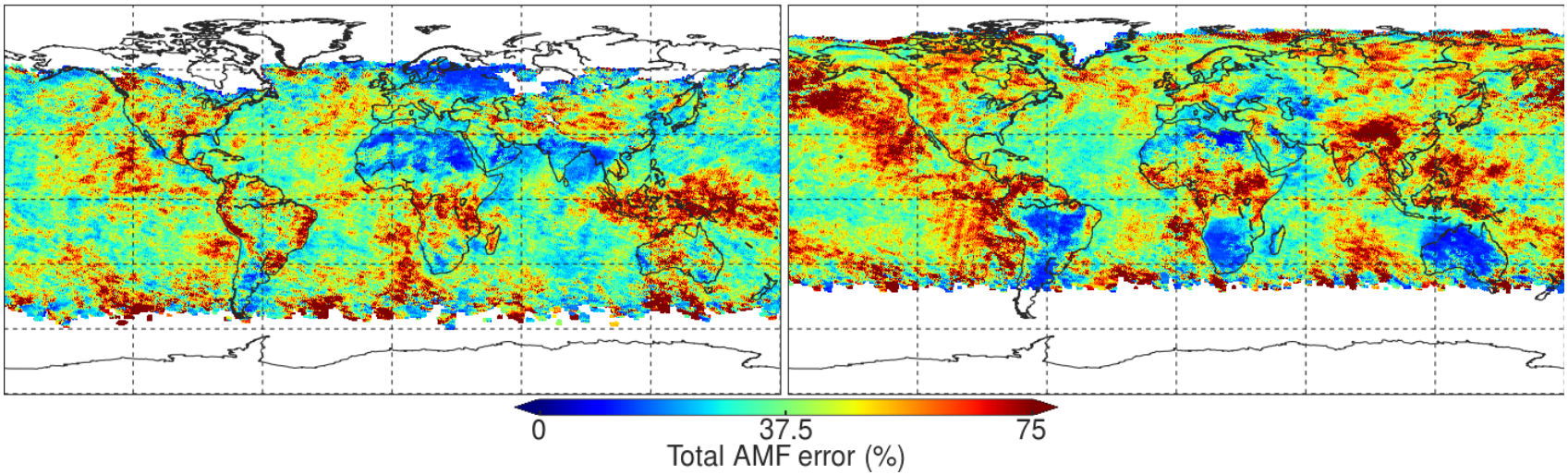
Combined effect of all AMF updates





- Use of GOME-2 cross-sections is small (uniform global decrease of 0-2%)
- Impact of TOMSv8 ozone climatology is also small ($\pm$2%)
- Median AMF difference is 3.5%, with 75% locations having an AMF 0-10% larger

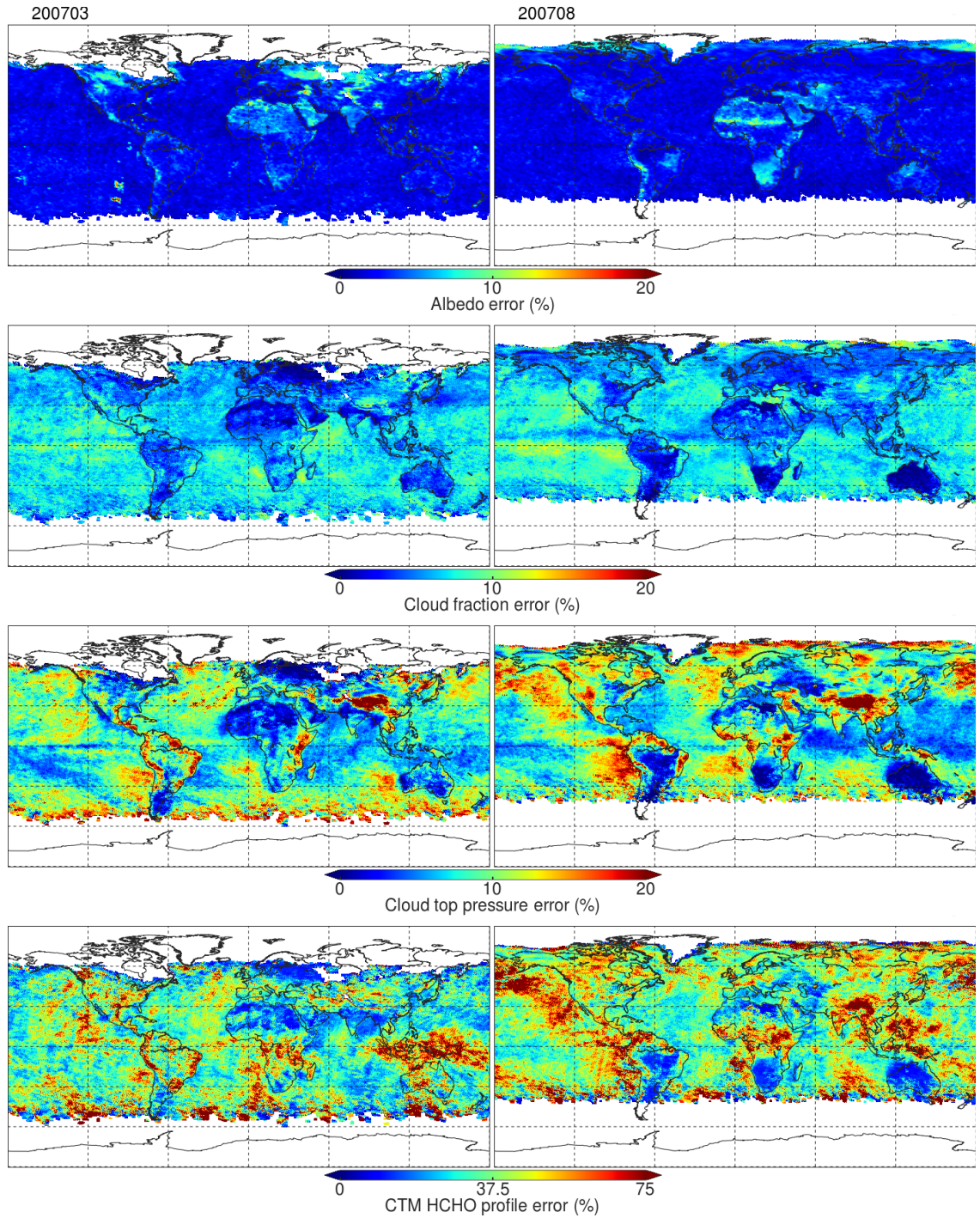
AMF Error Assessment



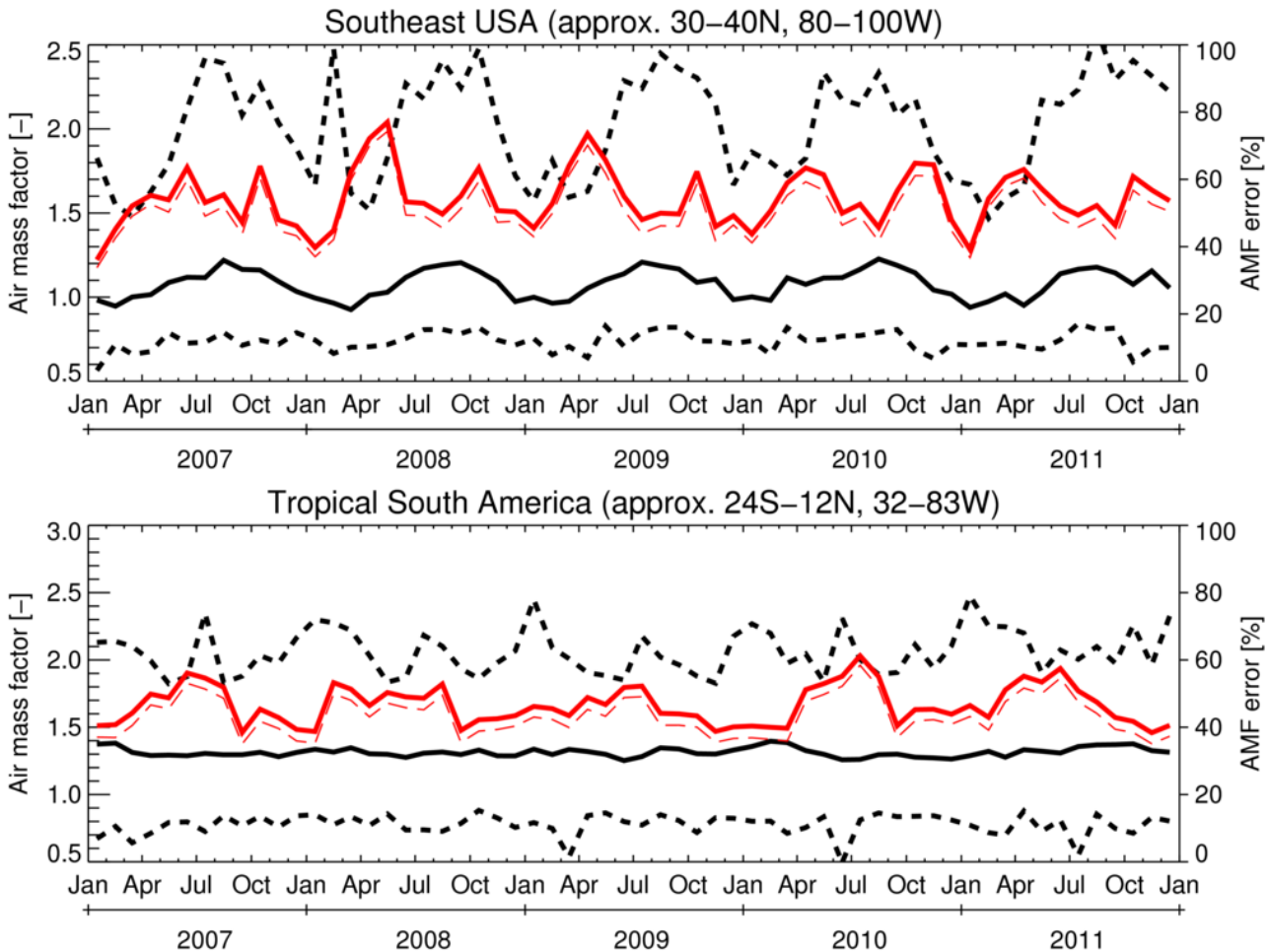
- Apply **all updates** and calculate AMF errors for each scene using :

$$\sigma^2_{\mathrm{AMF}} = \left(\frac{\partial AMF}{\partial A_s}\sigma_{A_s}\right)^2 + \left(\frac{\partial AMF}{\partial CF}\sigma_{\mathrm{CF}}\right)^2 + \left(\frac{\partial AMF}{\partial CTP}\sigma_{\mathrm{CTP}}\right)^2 + \left(\frac{\partial AMF}{\partial S}\sigma_S\right)^2$$

- **Key point: full radiative transfer calculation to determine sensitivity**
- Assigned uncertainties: σ_{A_s} from GOME-2 product; $\sigma_{\mathrm{CTP}} = 60$ hPa; $\sigma_{\mathrm{CF}} = 0.05$
- For σ_S we scale HCHO profile by $+25\%$ below and two model layers above peak layer, and by -25% for remaining layers above (this reflects likely profile uncertainty in tropics)
- Overall, **median AMF errors are about 50–60%**


200703
200708
0
10
20
Albedo error (%)
0
10
20
Cloud fraction error (%)
0
10
20
Cloud top pressure error (%)
0
37.5
75
CTM HCHO profile error (%)

Seasonal variation in AMF



Black solid = mean AMF; red solid = AMF error; red dashed = HCHO profile error

- AMF errors driven by HCHO profile uncertainty (in the algorithm. . .)
- If HCHO profile scaled by 10% in error calculation, median total error is about 30%

Summary

	Baseline AMF algorithm	**Updated AMF algorithm**
CTM	GEOS-Chem global $4^\circ \times 5^\circ$ grid	GEOS-Chem global $2^\circ \times 2.5^\circ$ grid
A Priori Profiles	Daily profiles (HCHO & AOD) - selected using centre coordinates	Daily profiles (HCHO & AOD) - area-weighted mean over footprint
Surface Pressure	GEOS-Chem ($4^\circ \times 5^\circ$)	GEOS-Chem ($2 \times 2.5^\circ$) - adjusted by area-weighted mean elevation
Surface Albedo	TOMS monthly climatology - Herman & Celarier [1997] - regridded to $4^\circ \times 5^\circ$ ($\lambda \sim$360 nm)	GOME-2 monthly climatology - Tilstra et al. [2014] - default $1.0^\circ \times 1.0^\circ$($\lambda =$340 nm) - area-weighted & time interpolated
Surface Elevation	n/a	GMTED2010 ($0.0083 \times 0.0083^\circ$)
LIDORT cross-sections	Fixed OMI cross section	Orbit specific GOME-2
LIDORT O_3 profile	U.S. Standard atmosphere	Monthly & latitudinal TOMS v8 climatology - scaled to coincident GOME-2 total ozone observations
Cloud Algorithm	FRESCO+	FRESCO+

Can use GEOS-Chem nested $0.5^\circ \times 0.667^\circ$ simulation for the Amazon

Median AMF difference is 3.5%

Some issues that need working on:

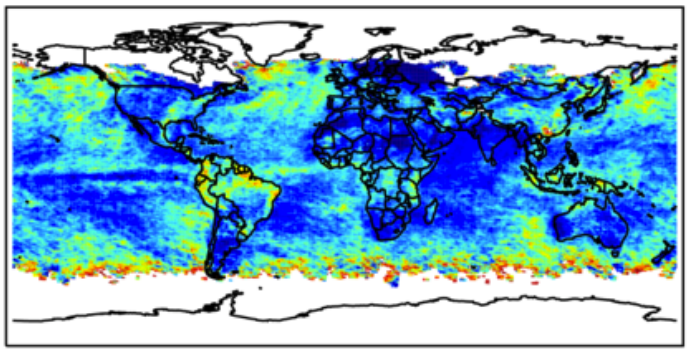
- Different reflectances in FRESCO+ which uses MERIS black sky albedo
- Different topography in FRESCO+ which uses GTOPO30
- Explicit aerosol correction may not be valid, as presence of aerosols maybe partly compensated by cloud algorithm
- Other instruments? GOME & SCIAMACHY (yes), OMI (possibly), TROPOMI (forget it)
- Other gases (e.g., NO_2, SO_2)? Yes.

Lastly

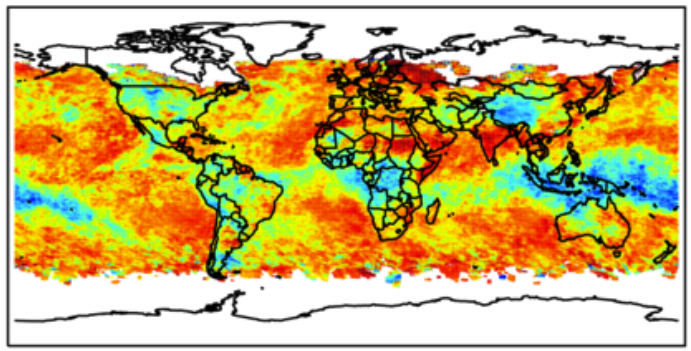
- **GOME-2 HCHO vertical columns require validation**
  We would like to collaborate with MAX-DOAS groups who have HCHO measurements
- **Upcoming 12 month PDRA position within EOS Group**
  Evaluating/updating retrieval and analysing HCHO data
  Contact: Michael Barkley (mpb14@le.ac.uk) or Hartmut Bösch (hb100@leicester.ac.uk)

Cloud Distributions

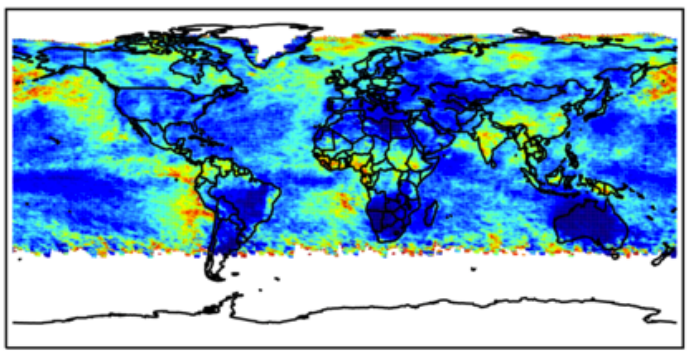
March 2007 - Cloud fraction



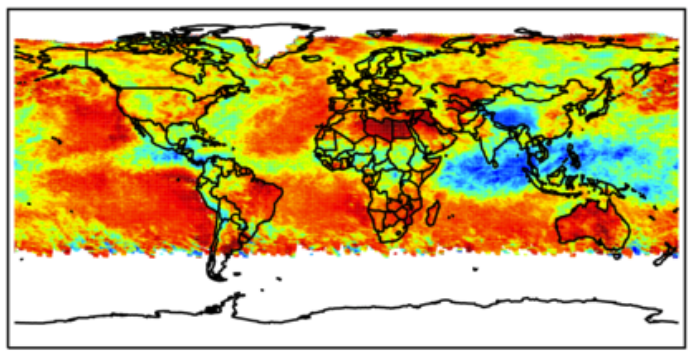
March 2007 - Cloud top height

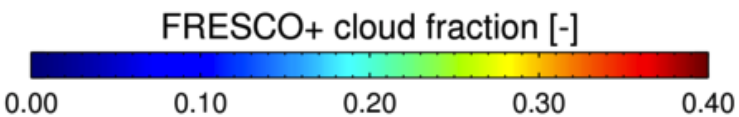


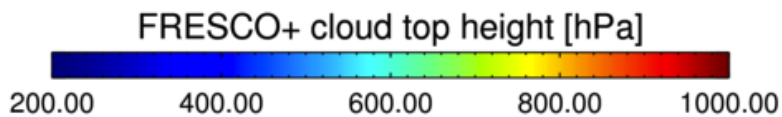
August 2007 - Cloud fraction



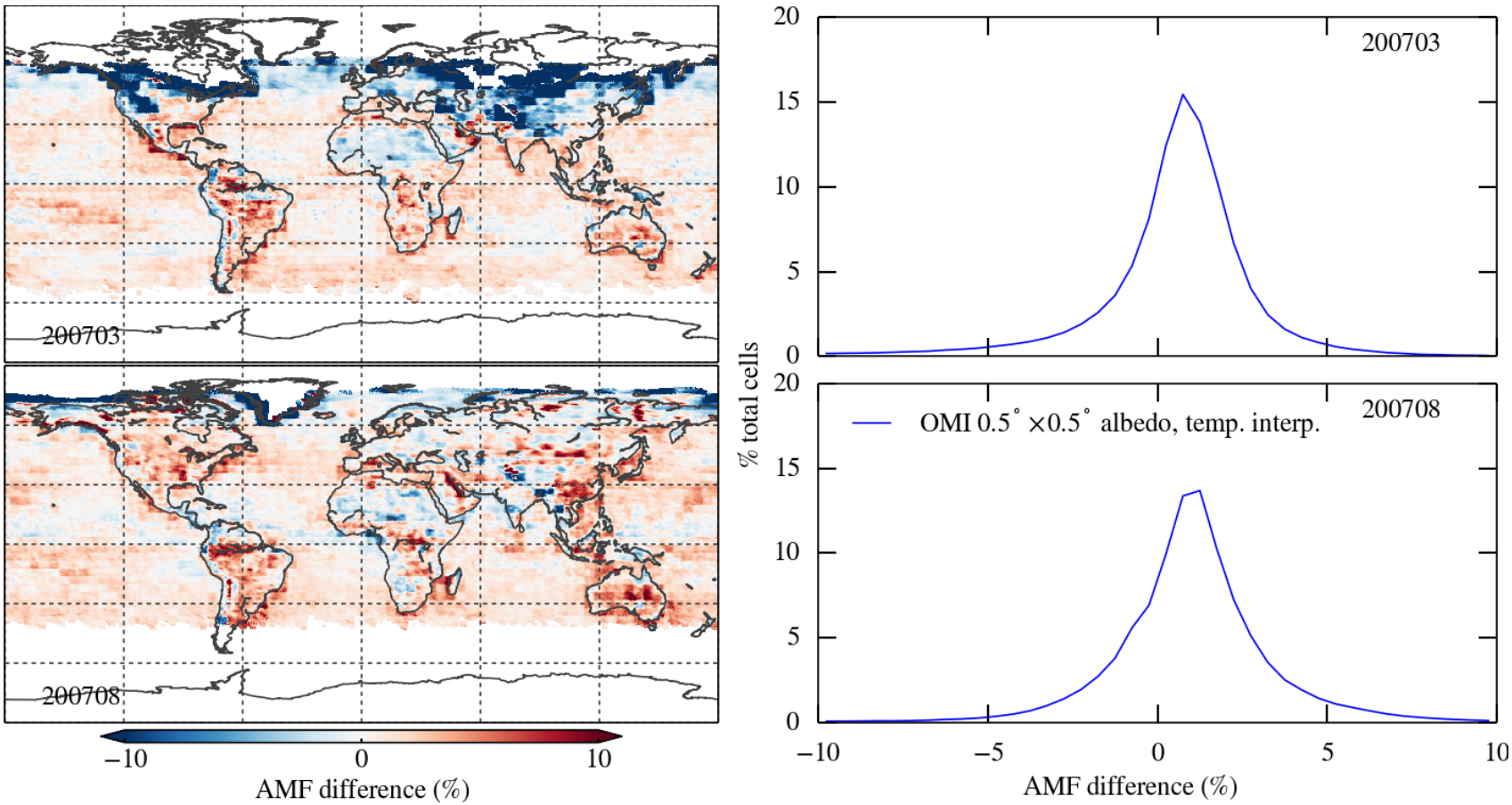
August 2007 - Cloud top height







OMI Surface Reflectance



TOMSv8 Ozone