Atmos. Chem. Phys. Discuss., 10, 6923–6953, 2010
www.atmos-chem-phys-discuss.net/10/6923/2010/

Atmospheric Chemistry and Physics Discussions

This discussion paper is/has been under review for the journal Atmospheric Chemistry and Physics (ACP). Please refer to the corresponding final paper in ACP if available.

Isoprene emissions modelling for West Africa using MEGAN

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Received: 27 January 2010 – Accepted: 28 February 2010 – Published: 11 March 2010

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Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

Isoprene emissions are the largest source of reactive carbon to the atmosphere, with the tropics being a major source region. These natural emissions are expected to change with changing climate and human impact on land use. As part of the African Monsoon Multidisciplinary Analyses (AMMA) project the Model of Emissions of Gases and Aerosols from Nature (MEGAN) has been used to estimate the spatial and temporal distribution of isoprene emissions over the West African region. During the AMMA field campaign, carried out in July and August 2006, isoprene mixing ratios were measured on board the FAAM BAe-146 aircraft. These data have been used to evaluate the model performance.

MEGAN was firstly applied to a large area covering much of West Africa from the Gulf of Guinea in the south to the desert in the north and was able to capture the large scale spatial distribution of isoprene emissions as inferred from the observed isoprene mixing ratios. In particular the model captures the transition from the forested area in the south to the bare soils in the north, but some discrepancies have been identified over the bare soil, mainly due to the emission factors used. Sensitivity analyses were performed to assess the model response to changes in driving parameters, namely Leaf Area Index (LAI), Emission Factors (EF), temperature and solar radiation.

A high resolution simulation was made of a limited area south of Niamey, Niger, where the higher concentrations of isoprene were observed. This is used to evaluate the model's ability to simulate smaller scale spatial features and to examine the influence of the driving parameters on an hourly basis through a case study of a flight on 17 August 2006.

This study highlights the complex interactions between land surface processes and the meteorological dynamics and chemical composition of the PBL. This has implications for quantifying the impact of biogenic emissions on the atmospheric composition over West Africa and any changes that may occur with changing climate.

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1 Introduction

Globally, isoprene (2-methyl-1,3,-butadiene) emissions are the largest source of reactive carbon to the atmosphere, completely dwarfing emissions of anthropogenic VOCs (Volatile Organic Compounds) (Lamb et al., 1987). Isoprene is produced by many woody and some herbaceous plant species and is the dominant VOC released from vegetation (Guenther et al., 1995). It is one of the primary reactants of tropospheric chemistry over continental areas exerting strong influences over tropospheric ozone (O_3) and hydroxyl radical (OH) chemistry, formation of organic nitrates and deposition of organic acids to rural areas (Fehsenfeld et al., 1992). Biogenic VOCs are also important in formation of Secondary Organic Aerosols (SOA) (Kavouras et al., 1998). Model studies suggest biogenic emissions of VOCs from West Africa to be important for tropospheric ozone (Aghedo et al., 2007; Pfister et al., 2008). Understanding the role of isoprene on tropospheric chemistry is also important since natural emissions are expected to change with changing climate and human impacts on landuse (Sowden et al., 2007).

Light and temperature exert primary control over isoprene production and emission. Isoprene emission is undetectable in the dark, but begins rapidly upon illumination and is fully induced within 30 min (Loreto and Sharkey, 1990; Monson et al., 1991). Once induced, isoprene production responds rapidly to variations in Photosynthetically Active Radiation (PAR). Monson et al. (1991) showed that during a light to dark transition, isoprene emission began dropping within 7 s and fell to zero within 5 min.

In West Africa, biogenic emissions are expected to peak in the summer monsoon period when solar radiation is at its highest and when vegetation cover reaches its maximum. At this time biogenic emissions are expected to be the dominant source of VOCs for much of the region since biomass burning is mostly limited to the dry, winter season and anthropogenic emissions are mostly confined to the major coastal cities (RETRO Emission Database: http://retro.enes.org/). Thus the West African Monsoon

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provides a relatively clean environment in which to the study biogenic emissions and their regional effects on tropospheric chemical composition.

Previous in-situ observations in this region during the monsoon period have been confined to the MOZAIC programme, which involved measurements of O_3, CO and total odd nitrogen (NO_y) on commercial aircraft flying in the upper troposphere (Sauvage et al., 2007) with vertical profiles as they descended and ascended into airports at Abidjan, Ivory Coast and Lagos, Nigeria (Sauvage et al., 2005). Other measurement campaigns in this region have been limited to the dry season (TROPOZ; Jonquieres et al., 1998, and DECAFE; Delmas et al., 1995).

As part of the AMMA (African Monsoon Multidisciplinary Analyses) project (AMMA, 2009), the first airborne measurements of isoprene concentrations were made over West Africa (Bechara et al., 2009; Murphy et al., 2010) thus providing the first in-situ data set with which to make a large scale evaluation of the biogenic emission inventories being used in Chemical Transport Model (CTM) studies of this area. The Model of Emissions of Gases and Aerosols from Nature (MEGAN) (Guenther et al., 2006) (MEGAN, 2010) is a state of the art dynamic emission model that is employed by many global and regional CTMs including some being used within the AMMA project. Previous observational constraints applied to the emissions calculated by MEGAN for Africa have been ground-based flux measurements at a few localised sites (e.g. fluxes from individual trees, or tower measurements from canopies) in southern (Otter et al., 2002, 2003; Greenberg et al., 2003; Guenther et al., 1996) and central Africa (Serca et al., 2001; Guenther et al., 1999; Greenberg et al., 1999; Klinger et al., 1998). This paper presents an evaluation of the emissions of isoprene calculated using MEGAN using observations of isoprene in the boundary layer over a large region of West Africa during the 2006 monsoon period and thus represents a significant advancement in the evaluation of MEGAN for this region.

2 Isoprene observations in West Africa

During July and August 2006 a multi-aircraft campaign took place over West Africa to observe the chemical composition of the troposphere and lower stratosphere as part of the AMMA project. Measurements on board 5 research aircraft provide the first detailed, in-situ, characterisation of the chemical composition of the troposphere in this region (Reeves et al., 2010). This paper focuses on the isoprene mixing ratios measured aboard the UK. Facility for Atmospheric Airborne Measurements (FAAM) BAe-146 research aircraft, which was based in Niamey, Niger. The measurements were taken during the 21 flights performed between 17 July and 17 August 2006 using a Proton Transfer Reaction Mass Spectrometer (PTR-MS) with a 10–15 s frequency and 15% accuracy (Murphy et al., 2010).

Figure 1 presents the portions of the flight tracks of the BAe-146 below 700 m a.s.l. and respective isoprene concentrations observed during the AMMA field campaign. These measurements were mostly taken during the daytime when an altitude of 700 m was within the boundary layer, but some of the data were collected at night when this would have been above the nocturnal boundary layer. Isoprene has an atmospheric lifetime of around 1–2 h during the daytime, so cannot be transported far from its source. The typical wind speed in the boundary layer was around 10 km h^{-1} such that advection would only have displaced the emissions by about 10 km before the isoprene concentrations would have been reduced considerably through chemical reaction. Measurements in the evening (Flight B219, 25 July) and early morning (B232, 14 August) show that the isoprene was transported around 1° of latitude (60 nautical miles or 120 km) northwards in the nocturnal flow, but that its mixing ratios had declined to around a third of their afternoon values. Therefore it is reasonable to assume that the observed distribution of isoprene concentrations provide a good indication of the spatial distribution of emissions.

The aircraft mostly flew across an area ranging from 0 to 4° E longitude and 5 to 17° N latitude. The spatial variation of the isoprene measurements shows that the

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higher concentrations were measured between 8 to 12° N. Broadly the concentrations drop off towards the coast in the south, and at 12 to 13° N. However, between about 11.1 and 11.5° N there was a small region where low isoprene concentrations were persistently observed.

3 Isoprene emissions modelling

The Model of Emissions of Gases and Aerosols from Nature, MEGAN, has been applied to estimate the isoprene emissions over West Africa for July and August 2006.

MEGAN is an emissions model that estimates the net emission rate of isoprene and other trace gases and aerosols from terrestrial ecosystems into the above-canopy atmosphere at a specific location and time (Guenther et al., 2006). Figure 2 presents its input/output structure.

MEGAN requires two types of inputs:

1. Landcover Data – monthly average Leaf Area Index (LAI), which is then averaged over the fraction of land area covered by vegetation (to give LAIv), Plant Functional Type (PFT), and Emission Factors (EF) at standard conditions. All of these are averaged for each grid location in the model domain. LAI values are needed for the months of the model simulation and the preceding month. These monthly LAI datasets are used to estimate the response of emissions to temporal variations in leaf age and LAI. Four different PFTs are considered by default in MEGAN – broadleaf trees, needle leaf trees, shrublands and herbaceous. The emissions factors can be considered within MEGAN as a function of the PFT at each location (PFT-specific emission factors) or pre-determined standard EFs for each location can be supplied as input.

2. Meteorological Data: Temperature and solar radiation variables output from the Meteorology-Chemistry Interface Processor (MCIP) are used to estimate the response of emissions to variations in temperature and light (Guenther et al., 2006).

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MCIP processes either WRF (Weather Research & Forecasting model) or MM5 (Mesoscale Model 5) output.

As a first approach, MEGAN has been applied to a regional domain with 40 km horizontal resolution (Sect. 3.1). A sensitivity analysis has also been performed aiming to evaluate the influence of the different input parameters to the isoprene emissions estimates (Sect. 3.2). To have a more detailed picture of the isoprene emissions distribution in the area where the majority of the airborne measurements were made, MEGAN was run for a smaller domain at a higher resolution (9 km) (Sect. 3.3).

3.1 Large scale MEGAN application over West Africa

The regional domain, approximately 2000 by 2000 km^2 wide (WA1), was defined taking into account the resolution of the input data available and the area where the BAe-146 flights were performed. The meteorological data were obtained from a WRF meteorological model regional (WRF, 2010) simulation for 2006 covering a 40 km horizontal resolution domain (Lat −5° to 20° and Lon −25° to 25°) over West Africa with 3 h time resolution (Flaounas et al., 2010). Consequently the domain used to run MEGAN had 48×48 cells centred at 11.62° Lat and 2.13° Lon, with 40 km (≈0.36°) horizontal resolution.

The MEGAN Community Data Portal (MCDP) includes datasets for LAIv for 2003 and PFT at 30 s horizontal resolution (i.e. 0.0083°) for the whole globe which were then averaged for the dimensions and resolution of the study domain. The PFT distributions vary according to plant type. Herbaceous species are spread throughout the domain although more concentrated in the middle latitudes of the domain. Needleleaf trees and shrubland fractions are greater at lower latitudes near the coast. Broadleaf tree fractions are very sparse in the study area.

Alternative LAI data sets for the years 2003 and 2006 from the MODIS satellite (MODerate resolution Imaging Spectroradiometer) were downloaded and converted into LAIv (using the MCDP PFT distributions). The MODIS LAI data were at 0.01°

horizontal resolution. The 2003 MODIS LAI was used for comparison with MCDP LAIv and the 2006 data were considered since the field observations of isoprene concentrations were made in 2006.

Figure 3 displays the three different sets of LAIv data used for this study. Comparing the two sources of LAIv for 2003 it can be seen that MODIS and MCDP LAI return similar fields, although the latter shows slightly higher values north of 12° latitude. All LAIv fields present a band of considerably high values in the northern part of the domain. Moreover, from the two MODIS datasets, lower values of LAIv are found for 2006 compared to 2003. Generally, the area with highest LAIv values are observed in the southwest region of the study domain.

The Emission Factors (EF) (for standard conditions of temperature and radiation) for some of the species considered by MEGAN are also available at the MCDP at 30 s horizontal resolution. These global data were averaged for the domain of interest as shown in Fig. 3 for isoprene. Isoprene emission factors decrease with latitude and are higher in the southeast part of the domain. High values of EF are given for some northern parts of this region, consistent with the LAIv fields, and as a consequence of the PFT spatial distributions. However, visual, subjective observations made on the BAe-146 flights in these regions suggested that very little vegetation was present. Certainly the observations of isoprene concentrations suggest very sparse coverage of isoprene emitting vegetation.

Figure 4 presents the results of the runs performed for domain WA1 (40 km resolution) using the three different sets of LAI data. These are also compared to the results obtained, for the year 2006, by Müller et al. (2007) who has estimated the global emissions of isoprene at 0.5° horizontal resolution for each year between 1995 and 2006, using MEGAN and a detailed multilayer 5 canopy environment model for the calculation of leaf temperature and visible radiation fluxes. Their calculation was driven by meteorological fields (air temperature, cloud cover, downward solar irradiance, wind speed, volumetric soil moisture in 4 soil layers) provided by analyses of the European Centre for Medium-range Weather Forecasts (ECMWF).

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Also in Fig. 4, the MEGAN estimated emissions are compared with observations of the mixing ratios of isoprene below 700 m. One has to apply some caution in comparing emissions with mixing ratios as transport, dilution and chemical transformation may impact atmospheric concentrations. However, given the short lifetime of isoprene this impact will be small and therefore such a comparison can be useful to evaluate model performance.

The model reproduces the dropping-off of emissions at the Niger-Benin border in excellent agreement with the observations. However, unlike the observed concentrations which imply virtually no emissions in the north of the region, the current MEGAN runs suggest a band of emissions around 15–16° N. This overestimation is not seen by Muller et al. (2007). Further MEGAN gives slightly greater emissions in the north (north of 12° N) when using MCDP LAI 2003 as opposed to MODIS LAI. These results reflect the differences in distribution of LAI from the two different data sources, as seen in Fig. 3. The latitudinal gradient is discussed further in Sect. 4.

The differences in estimated emissions between July and August are mainly due to the temporal variation of meteorological inputs. The higher emissions in August can be explained by the slight increase in temperatures and solar radiation modelled by WRF. Muller's results show the reverse pattern which is likely to be due to the different meteorological data used. The observed concentrations are not obviously different between the 2 months. It should be noted that meteorological analyses over West Africa are poorly constrained due to the lack of observations and are thus highly uncertain. This is illustrated by the study of Agusti-Panareda et al. (2009) which demonstrated the impact of assimilating the additional radiosonde data collected during AMMA into the ECMWF analyses. Other possible factors affecting the comparisons between the monthly variations on the observed isoprene mixing ratios and the MEGAN emissions could be processes not taken into account in the MEGAN simulation and factors affecting the lifetime of observed isoprene in the atmosphere.

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3.2 Sensitivity analysis

A set of simulations were designed to examine the impact of four factors, namely EF, LAIv (from MCDP), radiation and temperature, on the spatial distribution of the monthly average emission fields. These were done using domain WA1. A run was performed in which all of these 4 parameters were held spatially and temporally constant and a further 4 runs were made in which all but one of these parameters were held constant to a median value. To illustrate the contribution of each driving parameter to the spatial distribution of the emissions Fig. 5 shows percentage differences between each of these 4 runs and the run where all these parameters are held constant for August.

The EFs and the LAI clearly have the greatest impact on the spatial distributions of the monthly averaged emissions. They both contribute to the strong gradient observed around 12° N. However, it is the EFs that are responsible for the band of enhanced emissions centred around 16° N, which do not correspond to observed concentrations of isoprene. The meteorological parameters do not contribute significantly, in terms of spatial variation, to the simulated isoprene emissions when monthly averages are considered.

3.3 MEGAN application at higher resolution

Although the results presented so far provide an assessment of MEGAN on a large scale, they are not of high enough resolution to examine some of the smaller scale features exhibited in the observational data. The spatial resolution of 40 km and temporal resolution of 3 h were necessitated by the meteorological data used. To bypass this limitation the meteorological model MM5 has been applied to West Africa to get meteorological fields with higher spatial and temporal resolution. The PSU/NCAR mesoscale model MM5 is a limited-area, non-hydrostatic model with a multiple nesting capability, designed to simulate or predict mesoscale atmospheric circulation (Dudhia, 1993; Grell et al., 1994). MM5 has been used worldwide including the area of interest of this study, as a climatological application (Sijikumar et al., 2006).

MM5 has been run for 2 domains (27 and 9 km resolution respectively) using the two-way nesting capacity. The meteorological run has been performed for a two month period (July and August 2006) by consecutive three day simulations, with a spin-up of 6 h each, initialized with NCEP/FNL 1° resolution global data (NCEP, 2008). Based on the second MM5 domain, with 9 km resolution, a MEGAN domain was defined (WA2). MM5 returns the hourly temperature and radiation 2-D fields for the whole simulated period (July and August) needed for the MEGAN simulation.

In this higher resolution MEGAN simulation, apart from the meteorological fields, all the other input sources were the same as the lower resolution MEGAN simulation. Figure 6 shows the LAIv and EF fields averaged for the 9 km resolution domain based on the 0.01° LAI from MODIS 2006. Figure 7 compares the results for domain WA2 with the isoprene emissions estimates for domain WA1, both using LAI from MODIS 2006. North of 12° N, the higher resolution model gives lower emissions, whilst south of 12° N it gives higher emissions, which are spread most of the way to the coast, unlike the lower resolution run which has high emissions largely confined to northern Benin. This is true for both months, but particularly so for July. At high resolution, the spatial distribution more closely resembles that of the observed concentrations. A feature that was repeatedly observed during several flights was low isoprene mixing ratios in a small area in northern Benin around 11.1–11.5° N. Global land cover data (Source Data: © ESA/ESA Globcover Project, led by MEDIAS-France/POSTEL) suggest this area to be mostly rainfed cropland as opposed to forest or shrubland in surrounding areas. The high resolution model run also shows a similar feature in the calculated emissions that is present both for July and August.

The explanation for these changes is likely to be a combination of the higher resolution LAI and EF along with the change in the meteorological inputs. For example the minimum observed in northern Benin is captured by low EFs in the higher resolution input (Fig. 6) that is averaged out at the lower resolution (Fig. 3). Regarding the meteorological data, on average the temperature and radiation modelled by MM5 are slightly lower than estimated by WRF, which should lead to lower emissions (i.e. the opposite

effect). However, it appears that the greater spatial and temporal (hourly) variability of the higher resolution run and the fact that isoprene emissions are non-linear with respect to temperature, leads to higher emissions, whereas averaging these inputs in the lower resolution run leads to lower emissions. In terms of temporal evolution the simulation for WA2 returns higher isoprene emissions in July which was not observed in the previous simulation but is in agreement with Muller's results (Muller et al., 2007). This behaviour reflects a decrease in radiation levels between July and August in the MM5 data.

4 Monthly latitudinal variations

The model emissions from the four simulations performed (three for domain WA1 and one for domain WA2), along with those from Muller et al. (2007), have been averaged for the longitude range 2–3° E to better compare them with the observations (averaged for 0 to 3° E, but note that most are between 2–3° E) (Fig. 8). It should be noted that the observed concentrations at any given latitude exhibit a large range of values. This can mostly be attributed to very small scale variations that may be due to variations in vegetation, rates of mixing within the planetary boundary layer, or cloud cover. Also the observations were made at different times of day, with higher values generally observed close to midday (see below).

Despite the observed mixing ratios suggesting virtually no emissions over the bare soil (north of 12° N), all of the present study WA1 simulations suggest significant emissions in this region (due to the emission factors used; Sect. 3.2). Muller's simulation shows low emissions in this region apart from a small peak around 14°. The WA2 simulation stops around 15° N, but it gives lower emissions than any of the other simulations between and 13 and 15° N, more consistent with the observed mixing ratios.

The WA1 simulations estimate relatively low emissions between 7 to 10° N compared to 10 to 12° N, which is not implied by the observed isoprene emissions which show that high concentrations can exist at all of these latitudes. The WA2 simulation however

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results in a more even distribution of emissions between 7 to 12° N. Further the WA2 run also gives a slight dip in emissions in the region of rainfed cropland just north of 11° N, which is coincident with the lower mixing ratios observed on repeated flights at this latitude.

5 Hourly variability – case study

The comparative analysis of the isoprene emission estimates for the two resolutions simulated by MEGAN has revealed that the meteorological inputs may have a considerable influence on the emissions modelling, especially at a high temporal resolution. A case-study analysis has been performed aiming to contribute to a better understanding of these phenomena.

The results for 17 August 2006 have been investigated more deeply to analyse the temporal variation of measured and simulated parameters. On that day, the aircraft flew below 700 m altitude between 13:45 UTC and 14:30 UTC (low run of flight B235). Figure 9 presents the hourly fields of isoprene emissions estimated by MEGAN at 9 km horizontal resolution, and temperature and radiation simulated by MM5, for the corresponding hours of the low run. The surface fields show that the isoprene emissions are clearly driven by the radiation simulated. The areas where the radiation is higher correspond to higher emissions. Although emission and radiation patterns change from hour to hour, the spatial variability of the radiation is continuously represented in the spatial distribution of the isoprene emission estimates for any hour. The temperature drives the overall magnitude of the emissions (a temperature increase leads to higher emissions), but this meteorological parameter has little impact on their spatial variability, since the temperature itself does not vary significantly spatially.

The impact of radiation on the modelled isoprene emissions is further demonstrated in Fig. 10, where the model emissions and radiation extracted along the position of the flight track are plotted as a function of latitude for 14:00 UTC and 15:00 UTC. It is

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noticeable how the modelled radiation changes markedly along the flight track between the two hours and that the calculated emissions change in a similar manner.

Also in Fig. 10 are data collected on board the aircraft during this low level run. The observed isoprene mixing ratios exhibit several features that are not specifically related to temperature or radiation (Garcia-Carreras et al., 2010): there was a large scale downdraft around 10.5° N (associated with a Mescoscale Convective System – MCS – cumulonimbus cells to the west of the flight track), which is characterised by higher ozone mixing ratios, lower specific humidities (not shown) and lower temperatures (Fig. 10); the vegetation cover changes dramatically at around 12° N with rainfed croplands to the north and mostly shrubland and forest to the south, except between 11.0 and 11.5° N where there is rainfed cropland. The downdraft means that the air sampled around 10.5° N came from the free troposphere and thus we should exclude it from a comparison with the calculated emissions. The model has been shown to capture, to some degree, the features associated with the vegetation cover (see above), however this case study illustrates the strong influence of the model radiation. The emissions calculated for 15:00 UTC show some similarities to the observed isoprene mixing ratios, with lower values between 11.0 and 11.5° N and north of 12° N, but at this time the radiation follows a similar pattern. At 14:00 UTC, when the model radiation is very different, the modelled emissions again largely follow the radiation and exhibit a very different pattern to the observed isoprene mixing ratios.

Figure 10 also shows the downward short wave irradiance as observed on the aircraft. The data exhibited a great deal of variability such that much of it was flagged as not being good data (only the good data is shown). There is no clear relationship between the observed radiation and the isoprene, but if anything reductions in radiation and temperature (e.g. at 10.9° N and between 11.6 and 11.8° N) are associated with increases in isoprene mixing ratios.

Garcia-Carreras et al. (2010) examined the impact of land surface characteristics on the dynamics of the Planetary Boundary Layer (PBL) during this same flight. They used isoprene mixing ratios in the low level run as a marker of vegetation type which

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exhibited a good correlation with the fraction of forest/shrub cover. It appears that higher evapotranspiration over the forest/shrub-land, which emit more isoprene than neighbouring cropland, leads to increased latent heat fluxes, an associated decrease in sensible heat fluxes and thus to cool PBL temperature anomalies. It is supposed that the temperature gradients around these temperature anomalies then initiate land surface induced flows or vegetations breezes, which then form the convection. Since there is likely a strong vertical profile in isoprene, even within the mixed layer, shallow convection will push higher isoprene aloft, to the level of the aircraft. Further clouds will affect the chemistry through the photolysis rates, which in turn will also affect the lifetime of isoprene. At the scales of 10–50 km resolved by the aircraft, the presence of clouds, which control the radiation pattern at the surface, is linked to dynamical circulations in the boundary layer. These circulations are also redistributing isoprene on timescales comparable to its lifetime. Therefore the observations show patterns of isoprene that are dominated by the boundary-layer circulations, as well as the emissions. The transport of isoprene has not been modelled – just its emissions in MEGAN – and therefore the effects of mesoscale transport described by Garcia-Carreras et al. (2010) explain the lack of correspondence between isoprene observations and modelled emissions in Fig. 10.

This demonstrates that, in addition to strong relationships between meteorological factors and emissions of isoprene, there are very complex interactions between the land surface characteristics, the dynamics of the PBL and thus on the transport and chemistry of isoprene. Not only does this limit any comparison between calculated emissions and observed mixing ratios and isoprene, but it also illustrates the complexity of the processes that need to be represented in chemical transport models when simulating the impact of isoprene on tropospheric chemistry.

6 Conclusions

This paper presents an evaluation of the emissions of isoprene calculated using MEGAN for West Africa using observations of isoprene mixing ratios in the PBL. It represents a significant advancement in the evaluation of MEGAN for this region and thus is an important contribution to AMMA which aims to quantify the role of the West African Monsoon system in the emission of biogenic species and their impact on the global atmosphere.

The sensitivity analysis performed provides insight into the model behaviour, its response to input data changes and the influence of each driving variable on the model results. The LAI and emissions factors have the greatest impact on the large scale spatial distribution of the monthly average emission rates.

These large scale spatial distributions of emissions (at 40 km resolution) are generally in good agreement with those of the observed mixing ratios, with higher values over the forested regions south of 12° N and lower values to the north over the rainfed cropland and bare soil. There are, however, discrepancies identified over the bare soil around 16° N, which point to the need for improvements to the emission factors in this region.

The increase of horizontal resolution to 9 km allows MEGAN to simulate a region of reduced emissions over crop land of around 60 km in extent that is characterised by lower PBL isoprene mixing ratios as observed repeatedly on several flights. Increasing the model resolution both spatially and temporally also illustrates how the non-linearity of the relationship between the isoprene emissions and radiation and temperature can be an important factor in model calculations. Furthermore, for case studies involving temporal resolutions of around an hour, the meteorological parameters, which are known to be highly uncertain, are likely to be critical, and for features of a few tens of kilometres in length the meteorology may be coupled to the land surface characteristics.

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Acknowledgements. Based on a French initiative, AMMA was built by an international scientific group and is currently funded by a large number of agencies, especially from France, the UK, the US and Africa. This work was funded by the EU and by the UK Natural Environment Research Council through the AMMA-UK Consortium grant and the National Centre for Atmospheric Science.

The authors are grateful to Alex Guenther and Tiffany Duhl for their help to run MEGAN and to Emmanouil Flaounas and Sophie Bastin (IPSL/Service d'Aeronomie, France) for the WRF meteorological modelling results provided.

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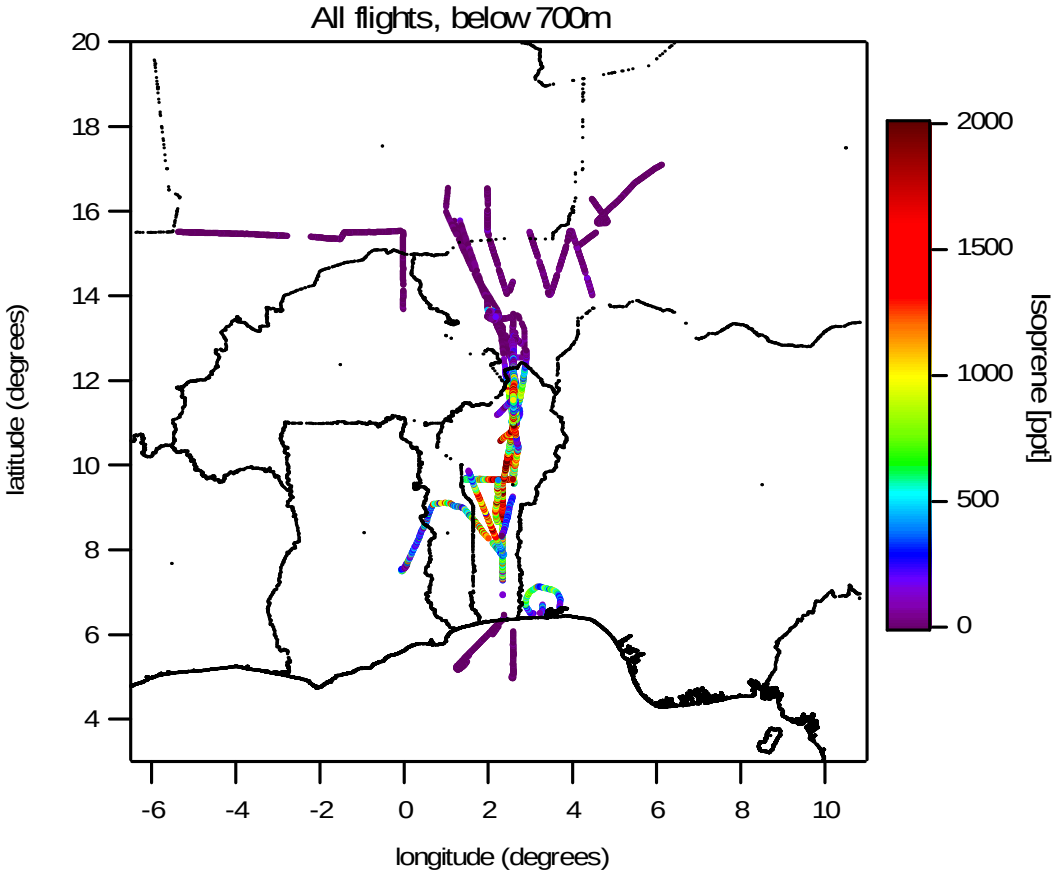

Fig. 1. FAAM BAe-146 aircraft flight tracks coloured by isoprene concentrations measured below 700 m during the AMMA field campaign in July and August 2006.

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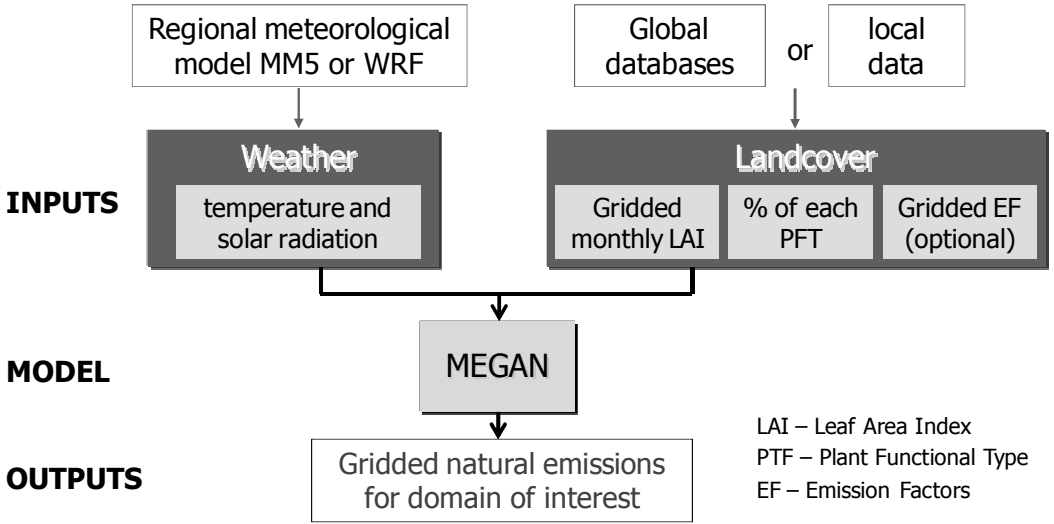

Fig. 2. MEGAN model structure including input/output information.

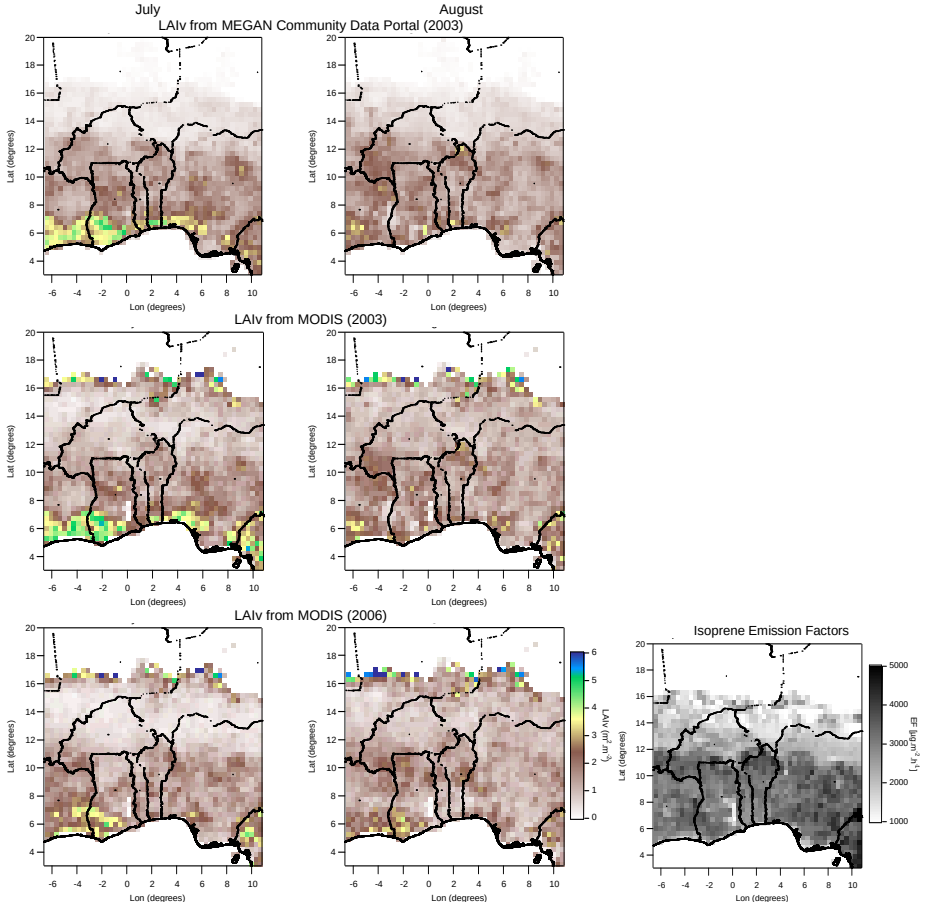

Fig. 3. Spatial distribution of the isoprene emissions factors and the three different sets of LAIv data, MCDP (2003) and MODIS (2003 and 2006) for the 40 km horizontal resolution domain.

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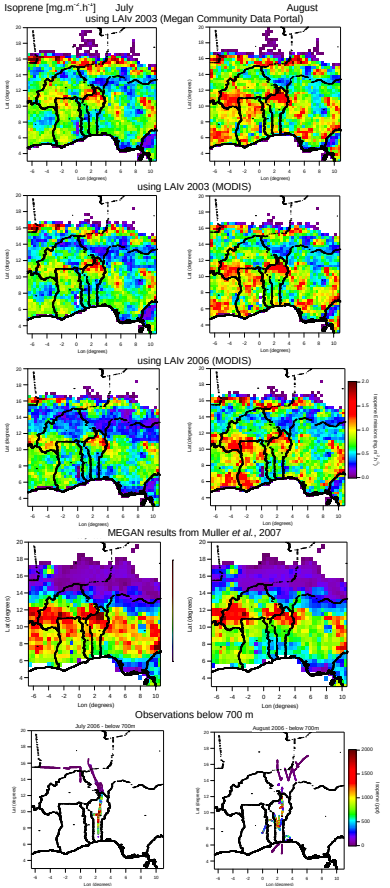

Fig. 4. Isoprene emissions (mg m^{-2} h^{-1}) estimated by MEGAN (domain WA1) using three LAI fields from two different sources (LAI MCDP, LAI MODIS 2003 and 2006) and obtained by Muller et al. (2007), for the year 2006, and isoprene concentrations (ppt) measured below 700 m. These are monthly averages and the data from the current study are calculated from 3 hourly output.

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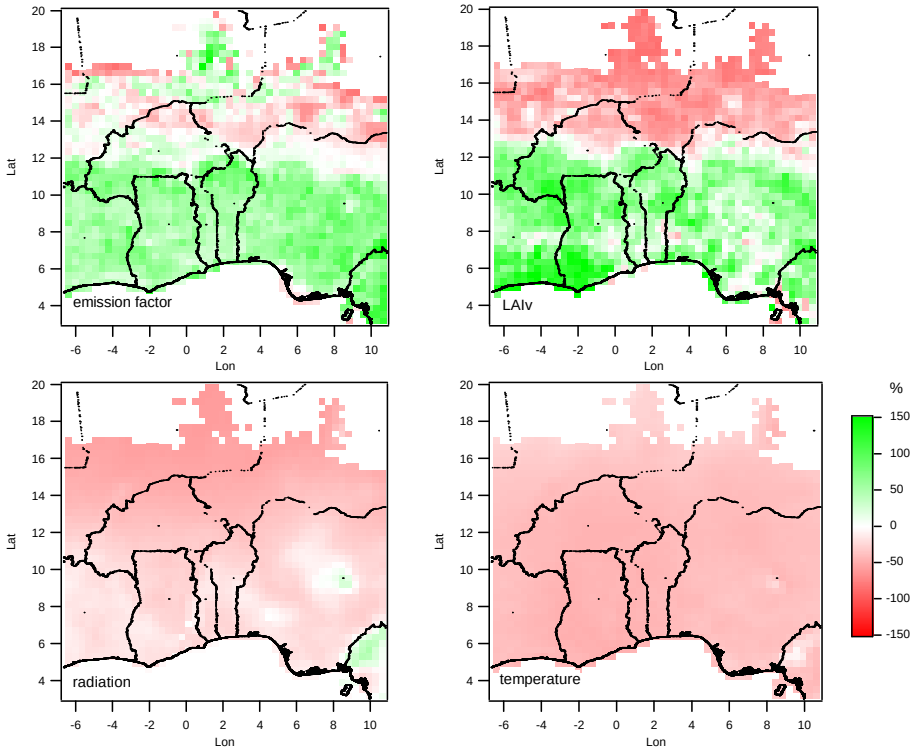

Fig. 5. Spatial distribution of the differentials in percentages obtained for August between each one of the four hypothetical runs performed with all but one variable constant and a run where all variables are constant in space and time, (e.g. the top left hand side plot refers to the differences in percentage between the run with all variables constant except emission factors and the run with all inputs constant).

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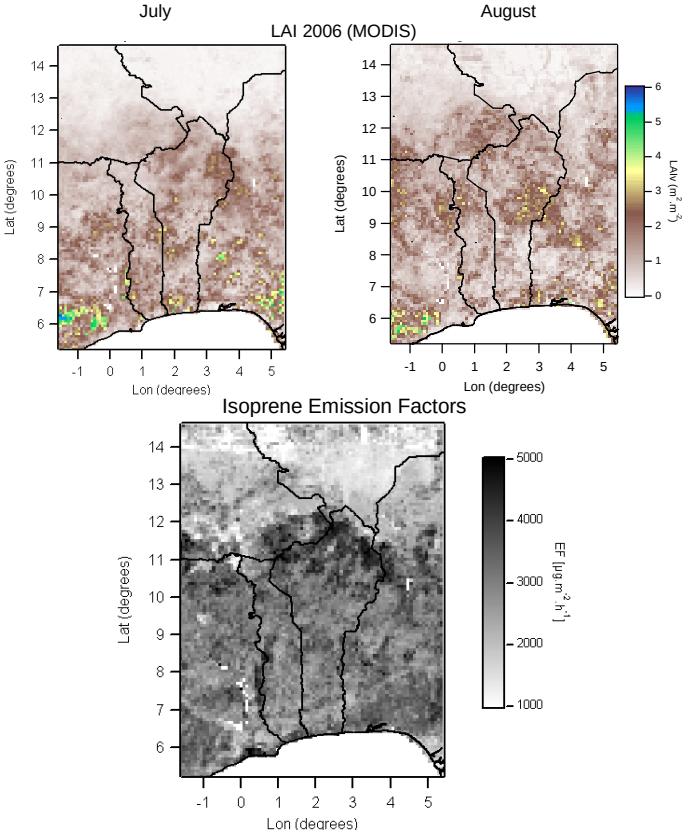

Fig. 6. Spatial distribution of the isoprene emissions factors and the two different sets of LAIv data, MCDP (2003) and MODIS (2006) for the 9 km horizontal resolution domain.

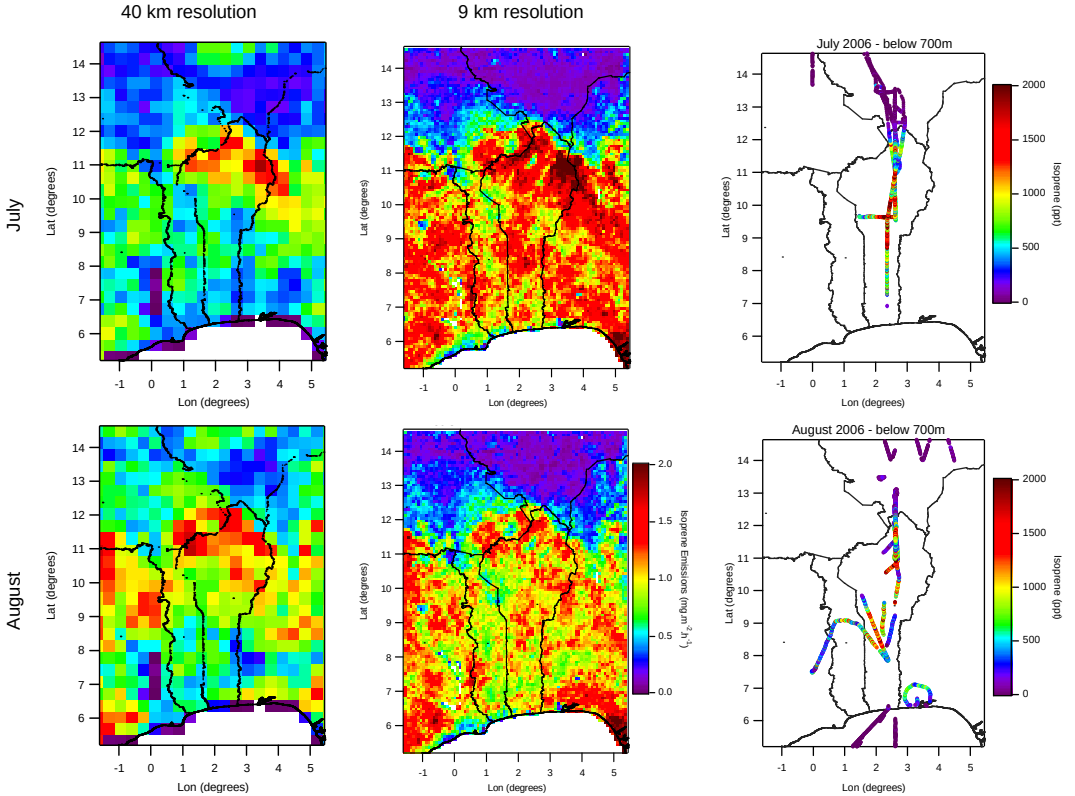

Fig. 7. Isoprene emission (mg m^{-2} h^{-1}) estimates for 40 and 9 km resolution MEGAN applications and isoprene concentrations (ppt) measured during the AMMA project field campaign on board the FAAM BAe-146 aircraft in July and August 2006.

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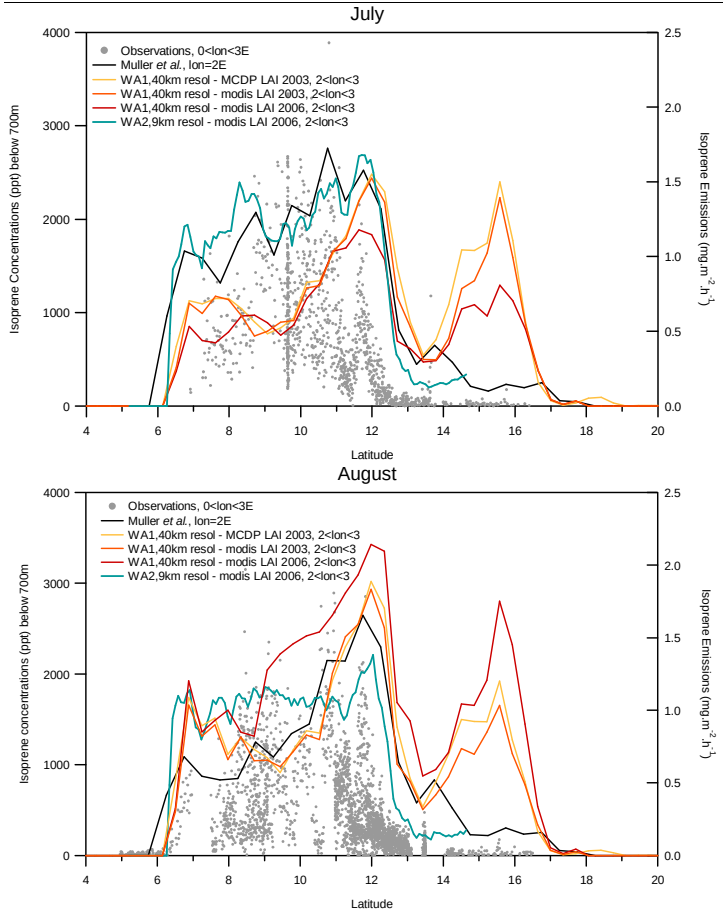

Fig. 8. Latitudinal variation of isoprene emissions for WA1 (based on the three sources of LAI data and on results obtained by Muller et al., 2007) and for WA2 (LAI MODIS 2006), and observed concentrations in July and August 2006.

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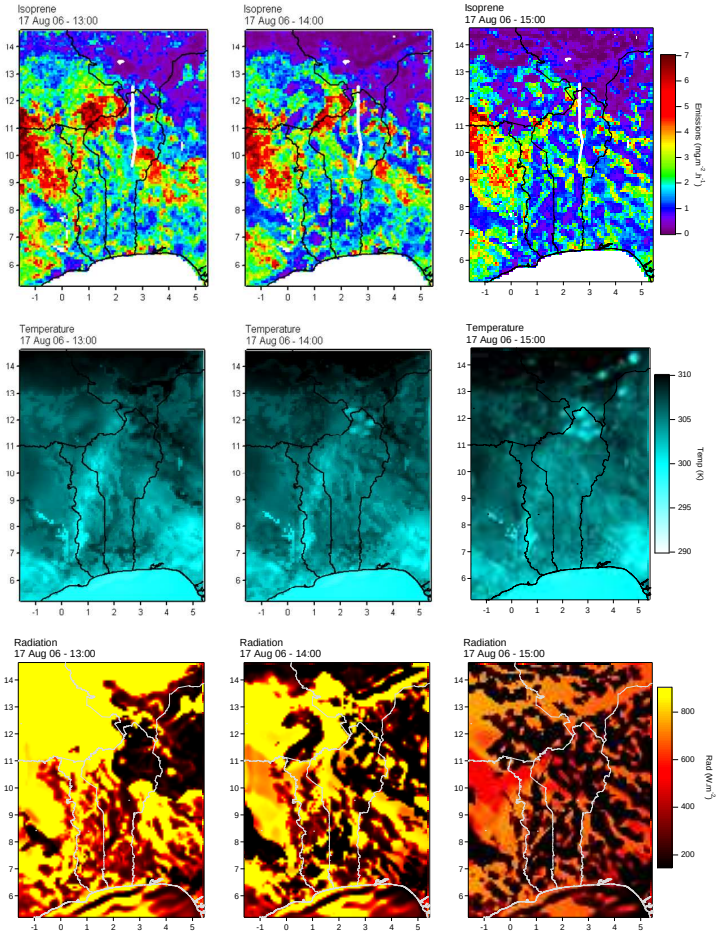

Fig. 9. Hourly surface fields of isoprene emissions (mg m^{-2} h^{-1}) estimated by MEGAN at 9 km horizontal resolution, and temperature (K) and radiation (W m^{-2}) simulated by MM5 at 13:00, 14:00 and 15:00 for 17 August 2006. The flight track of the low level run of flight B235 is shown by the white line in the top panel.

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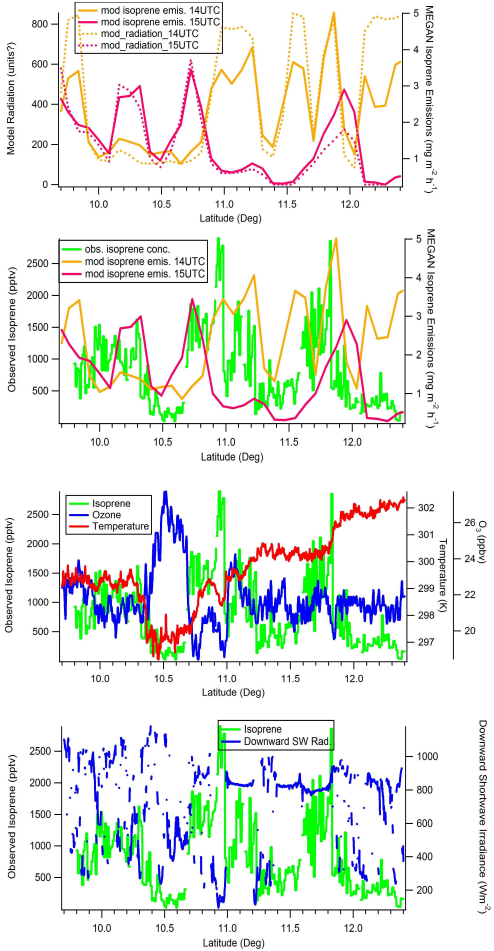

Fig. 10. The latitudinal variation of various parameters along the flight track of the low level run of flight B235 between 13:35 and 14:30 UTC on 17 August 2006: modelled isoprene emissions rates and MM5 radiation for 14:00 and 15:00 UTC, observed isoprene and ozone mixing ratios, temperature and downward short wave radiation.