# Impact of Spaceborne Observations on Tropospheric Composition Analysis and Forecast (ISOTROP) 

Comparison of cloud parameters calculated using ECMWF and ARPEGE/MOGACE input variables for use in retrievals

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| ABSTRACT: <br> The aims of the document are: <br> 1. To describe how cloud water content variables from the meteorological part of the Nature runs can be used to provide effective (radiative) cloud cover and cloud top heights needed to compute the synthetic satellite observations. <br> 2. To compare the cloud distributions from ECWMF (used by LOTOS-EUROS) and ARPEGE/MOCAGE. |  |  |  |
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## 1. Comparison of the meteorological variables taken from the data archives

| Variable name | Comments | Unit |
| :--- | :--- | :--- |
| Pressure $\left(p_{l}\right)$ of the layer | Surface pressure and <br> sigma hybrid co-ordinates | hPa |
| Temperature |  | K |
| Specific humidity | SH | $\mathrm{kg} / \mathrm{kg}$ |
| Liquid Water Content $(*)$ | LWC | $\mathrm{kg} / \mathrm{kg}$ |
| Ice Water Content $\left.{ }^{*}\right)$ | IWC | $\mathrm{kg} / \mathrm{kg}$ |
| Cloud Cover | Fraction | $-(0-1)$ |

Table 1: Meteorological variables needed for the calculation of cloud optical depth. It should be noted $\left(^{*}\right)$ that both LWC and IWC are calculated online in the MOCAGE model rather than taken from the ARPEGE meteorological data archive.

In order to calculate values of cloud optical depth ( $\tau_{\text {cld }}$ ) for each atmospheric layer defined in any model requires the use of some standard meteorological variables which are typically available in meteorological data archives. From these $\tau_{\text {cld }}$ values the calculation of effective, optical cloud parameters for use in indexing precalculated look-up table radiances can then be performed. Table 1 provides an overview of these parameters and the SI units relevant to each of the variables.


Figure 1: The distribution in the column integrated IWC,LWC and SH as provided from ECMWF and MOGAGE, except for SH which is provided from ECMWF and ARPEGE.

Figure 1 shows the column integrated SH, LWC and IWC values which were provided for this inter-comparison of cloud properties. Two weekly periods are chosen, namely $1-7^{\text {th }}$ June 2003 and $8^{\text {th }}-14^{\text {th }}$ December 2003 with a 6 hourly resolution. For the IWC and the LWC the values are representative of the cloudy fraction of any grid cell. The difference in the horizontal resolutions between the datasets $\left(0.25^{\circ} \times 0.25^{\circ}\right.$ for ECMWF versus $0.2^{\circ} \times 0.2^{\circ}$ for MOCAGE and ARPEGE)
means that the total number of instances $(\mathrm{N})$ is normalized using the ratio of $\mathrm{N}_{\mathrm{ECMWF}} / \mathrm{N}_{\text {MOCAGE }}$ or $\mathrm{N}_{\mathrm{ECMWF}} / \mathrm{N}_{\text {ARPEGE }}$, respectively. Comparing the distribution in the column integrated SH values shows that ARPEGE exhibits a rather 'wetter' atmosphere compared to ECMWF. This feeds through into both the IWC and LWC values. For the IWC the distribution in the MOCAGE model values is somewhat less than those in the ECMWF model, especially for June. For the LWC values MOCAGE and ECMWF have a similar range in their distributions, with MOCAGE generally having higher LWC values.
2. Comparison of Liquid Water path and Cloud Optical Density terms


Liquid Water Path

Figure 2: The distribution in the maximum LWP values averaged below 500 hPa for $1^{\text {st }}-7^{\text {th }}$ June (top) and $8^{\text {th }}-14^{\text {th }}$ December, 2003 (bottom).

For the calculation of cloud optical properties of liquid water clouds we use a number of different parameterizations which are taken from the literature. The LWC values are converted into the corresponding Liquid Water Path ( $\mathrm{g} / \mathrm{m} 2$ ) using the height of each model layer upon which the LWC is provided. This is subsequently used to determine the effective cloud droplet radius per model layer according the MacFarlane et al (1992). These quantities are then used in the parameterization of

Slingo (1989), which is commonly adopted for this purpose in climate models, and calculates both a scattering and absorption component for liquid water clouds, using the effective radius. For ice water clouds we calculate the smaller scattering component using the parameterization of Fu (1996). We then sum these quantities at each model layer to provide a summed $\tau_{\text {cld }}$ for further use.

Figure 2 shows comparisons of the resulting maximum LWP values resulting from both of the meteorological datasets which occur below 500 hpa . It can be seen that the MOCAGE LWP is significantly smaller than the ECMWF LWP. This is in contrast to previous studies which have found ARPEGE values to be 2-4 times larger than those in ECMWF during an inter-comparison exercise at a measurement site in the USA (Lenderink et al, 2004). It should be noted that the LWC values used here are not from the ARPEGE model itself but from parameterizations included in MOCAGE, which use the SH to calculate an associated value for LWC. Additionally, the distribution of the ECMWF LWP has previously been found to be more consistent with observations compared to those in the ARPEGE model (Roebeling et al., 2008).


Figure 3: The distribution in the column integrated $\tau_{\text {cld }}$ weighted by the cloud fraction.

For the purpose of calculating the incident radiative flux below any cloud layer the $\tau_{\text {cld }}$ values are subsequently weighted by the cloud fraction for each respective grid cell, where both the cloudy and clear part of any grid cell contribute to the total incident flux at both higher and lower altitudes due to enhanced scattering. Figure 3 shows a comparison of $\tau_{\text {cld }}$ scaled with the cloud fraction $\left(f_{\text {cld }} \tau_{\mathrm{cld}}\right)$ for both of the
chosen weeks. Considering that the SH values provided by ARPEGE are generally higher than those provided in ECMWF, it is surprising that the spread in the $f_{\text {cld }} \tau_{\text {cld }}$ is smaller than the corresponding spread in the ECMWF $f_{\text {cld }} \tau_{\text {cld }}$ values. This maybe explained by both the distribution and magnitude of the cloud cover data provided in both meteorological datasets.


Figure 4: Differences in instantaneous cloud fraction between the ECMWF and ARPEGE meteorological data at $\sim 850 \mathrm{hPa}$.

To exemplify these differences we show examples in the instantaneous distribution in cloud cover ( $f_{\text {cld }}$ ) for 12:00 UT on $1^{\text {st }}$ June (top) and $8^{\text {th }}$ December, 2003 (bottom) in Figure 4. It can be seen that although the geographical distribution is rather similar between both of the datasets, the cloud fraction provided by ARPEGE is considerably small than that of ECMWF. The ECMWF data, which exhibits maximal values of $100 \%$, shows much more temporal variability than ARPEGE, which exhibits maximal values of $\sim 85 \%$. The maximal values in the ECMWF are typically not co-located with those in the ARPGEGE data. This is in spite of both the smaller grid cells in the

ARPEGE dataset and the higher specific humidity values shown in Fig. 1. This goes against the findings published in a number of previous intercomparison exercises (Lenderink et al, 2004; Siebesma et al, 2002), albeit over more convective regions. This results in a much lower, but more diffuse, set of $f_{\text {cld }} \tau_{\mathrm{cld}}$ values in the MOCAGE dataset, where the corresponding values are shown in Figure 4.

Figure 5 shows the total integrated cloud OD weighted with the corresponding cloud fraction. It can be seen that the low $f_{\text {cld }}$ values shown in Fig. 4 for MOCAGE feed through into the cloud weighted OD values resulting in values for the ECMWF meteorological data being typically an order of magnitude larger than those in MOCAGE. This has the potential to introduce significant differences in the amount of scattered radiation at any location (i.e. alter the penetration depth of photons through the column).


Figure 5: Instantaneous $\tau_{\text {cld }}$ weighted by the cloud fraction and integrated over all layers.

Figure 6 shows a comparison of the maximum cloud fraction in each column for both of the selected periods. It can be seen that for June 2003 no fully clouded atmospheric
columns exist in the ARPEGE data in spite of the smaller horizontal resolution. For ECMWF there is a rather homogenous spread in values for both seasons, whereas with ARPEGE there are $\sim 10 \mathrm{x}$ as many instances where a maximum cloud fraction of between 0.03-0.2 occurs (relatively low cloud cover). This will have an effect on the photo-dissociation rates which occur in any chemistry-transport model adopting such profiles (e.g Tie et al, 2003). A similar in the distribution of cloud cover was found in the cloud-net FP5 EU-funded project for the summer of 2002.


Figure 6: The distribution in the maximum cloud fraction defined in each column from both the ECMWF and the ARPEGE meteorological models.

To examine the temporal correlation of the cloud cover contained in both of the datasets we compare corresponding values taken at specific locations across Europe. The $0.25^{\circ}$ (ECMWF) and $0.2^{\circ}$ (ARPEGE) cloud cover data is sorted with respect to both latitude and longitude using a $0.5^{\circ}$ and $1.0^{\circ}$ target grid, respectively, providing an array of 50 by 50 individual points across for the whole European domain shown in Figs 4 and 5 for both of the meteorological datasets. The values extracted are for 12:00 UT and include all 7 days of data for both of the selected weeks are sorted, thus comparisons are made for 350 individual points per latitude. Figure 7 shows the resulting correlation which occurs for both seasons at 6 different latitudes (with all longitudes being included on the same plot to make the comparisons statistically robust). The corresponding Pearson's correlation coefficients and associated covariance values are provided in Table 2.
Examining the distribution of points across latitudes shows that there is a similar behaviour in the correlation between values from the Mediterranean up to the Baltic region, where the wide range of values in the ECMWF dataset are typically correlated
with values of 0.2 or below in the ARPEGE dataset. The pattern is similar for both of the months shown, although the scatter is much larger during the winter (i.e.) the ARPEGE cloud cover shows more variability compared to the summer. This is reflected in the corresponding values for the correlation coefficients provided in Table 2, where the coefficients for December are somewhat higher than those for June, which are essentially anti-correlated.


Figure 7: Correlation plots between cloud cover values extracted at 12:00 UT from both of the meteorological datasets at 6 selected latitudes ( $36.5^{\circ}, 41^{\circ}, 46^{\circ}, 51^{\circ}, 56^{\circ}$ and $60^{\circ}$ ). Comparisons are shown for both June (top six panels) and December (bottom six panels).

| Latitude | Pearsons R <br> June | Co-variance | Pearsons R <br> December | Co-variance |
| :---: | :---: | :---: | :---: | :---: |
| 36.5 | 0.216 | 0.008 | 0.305 | 0.014 |
| 41 | -0.122 | -0.011 | 0.603 | 0.022 |
| 46 | 0.166 | 0.009 | 0.446 | 0.024 |
| 51 | 0.371 | 0.018 | 0.446 | 0.026 |
| 56 | 0.257 | 0.016 | 0.399 | 0.016 |
| 60 | 0.520 | 0.025 | 0.436 | 0.029 |

Table 2: Pearsons correlation co-efficients and co-variance values for the correlation plots shown in Figure 7.

## 3. Method of calculating terms for extracting radiances out of the pre-calculated look-up tables

The effective cloud pressure ( $P_{c l d}^{\text {eff }}$ ) can be calculated based on weighting factors equal to the $\tau_{\text {cld }}$ of each layer accounting for the $f_{\text {cld }}$ of that respective layer, thus:

$$
\begin{equation*}
P_{c l d}^{e f f}=\sum_{l} \rho_{l} f_{l} \tau_{l} / \sum_{l} f_{l} \tau_{l} \tag{1}
\end{equation*}
$$

In a similar way the profile-mean cloud cover can be calculated which is based on weighting factors equal to the optical depths of each layer, thus:

$$
\begin{equation*}
f_{c l d}^{\text {mean }}=\sum_{l} f_{l} \tau_{l} / \sum_{l} \tau_{l} \tag{2}
\end{equation*}
$$

The total $\tau_{\text {cld }}$ for the cloudy fraction of any model grid column may then be introduced as:

$$
\begin{equation*}
\tau_{\text {tot }}=\sum_{l} f_{l} \tau_{l} / f_{c l d}^{m e a n} \tag{3}
\end{equation*}
$$

The satellite cloud retrieval algorithm estimates an effective cloud cover based on the assumption of an optically thick cloud. Therefore, this effective cloud cover will typically be smaller than that described in Eqn. (2), thus:

$$
\begin{equation*}
f_{c l d}^{e f f}=f^{*} f_{\text {cld }}^{\text {mean }} \tag{4}
\end{equation*}
$$

Here $f^{*}$ refers to the cloud covered part of the model grid column only. The estimated radiance received by the satellite is used to fix the effective cloud fraction. In terms of the measured reflectance $(r)$, clear-sky reflectance $\left(r_{c l r}\right)$ and fully covered (thick cloud) reflectance ( $r_{c l d}$ ), thus:

$$
\begin{equation*}
f^{\text {retreived }}=\left(r-r_{c l d}\right) /\left(r_{c l d}-r_{c l r}\right) \tag{5}
\end{equation*}
$$

Using the DISAMAR radiative transfer model a relationship has been derived between $\tau_{\text {cld }}$ and the average reflectance over the wavelength range $400-465 \mathrm{~nm}$ using
representative geometry and assuming a surface albedo of $\sim 5 \%$ and a solar zenith angle $=50^{\circ}$. The Henry-Greenstein function was used to describe the cloud, where there was no dependency on the wavelength was included and adopting a single scattering albedo $=1.0$ with the Henry Greenstein parameter $=0.7$. Fitting the resulting dependence of the average reflectance on $\tau_{\text {cld }}$ gave the following:

$$
\begin{equation*}
R_{c l d}\left(\tau_{\text {tot }}\right)=0.95319033-\frac{1.0}{1.22462777+\left(0.00381833 * \tau_{\text {tot }}+0.1650632\right) * \tau_{\text {tot }}} \tag{6}
\end{equation*}
$$

Using this fit we can compute the $f^{*}$ value for the cloudy part of the model footprint thus:

$$
\begin{equation*}
f^{*}=\frac{r_{c l d}\left(\tau_{t o t}\right)-r_{c l d}(0)}{r_{c l d}(\infty)-r_{c l d}(0)} \tag{7}
\end{equation*}
$$

From the fitting procedure the values for $r_{c l d}(0)$ and $r_{c l d}(\infty)$ are 0.13661567 and 0.95319033 , respectively.

It should be noted that Eqn. 7 based on Eqn. 6 is only approximate for other geometric parameters, cloud assumptions and surface albedos to those that are listed above and chosen for the derivation of the fitting parameters. However, the basic aspect is a rescaling of the average cloud fraction throughout the column through $f^{*}$ and a 'cross-over' from optically thin to optically thick clouds for the range $\tau_{\mathrm{cld}}=2$ 10, see Fig. 8 This 'cross-over' region will not be very parameter dependent and the approach should provide a meaningful derivation of the effective cloud properties based on the meteorological input parameters.

Finally we define the optical properties which are used for indexing the look-up tables. Based on $P_{\text {cld }}^{\text {eff }}$ and $f_{\text {cld }}^{\text {eff }}$, the cloud radiance fraction ( $\omega$ ) can be calculated, thus:

$$
\begin{equation*}
\omega=\frac{f_{\text {clf }}^{\text {eff }} r_{c l d}}{f_{\text {cld }}^{e f l d}}+\left(1-f_{c l d}^{e f f}\right) r_{c l r} \tag{8}
\end{equation*}
$$

Here, the fully clear and cloudy sky reflectances depend on the satellite geometry, the surface/cloud albedo and $P_{c l d}^{\text {eff }}$.


Figure 8 DISAMAR simulations and fitted function as given in Equation 6. The optical depths $\tau$ are shown on the horizontal on a logarithmic scale. On the vertical we show
the reflectance (left) or sun-normalised radiance (right).

## 4. Comparison of effective cloud pressure ( $P_{c l d}^{\text {eff }}$ )

The value of $P_{c l d}^{\text {eff }}$ provides information related to where in the atmosphere the dominant $f_{\text {cld }} \tau_{\text {cld }}$ value occurs. Values which are $<400 \mathrm{hPa}$ indicate cirrus cloud coverage and those $>750 \mathrm{hPa}$ indicate tropospheric clouds in the boundary layer. Figure 9 shows comparisons of $P_{\text {cld }}^{\text {eff }}$ calculated using input from both ECMWF and ARPEGE. Although the general shape of the distribution is rather similar, more of the optical dense cloud banks occur in the lower atmosphere (boundary layer) when using the ECMWF input parameters, as would be expected.

Pcloud values


Figure 9: Comparison of $P_{\text {clf }}^{\text {eff }}$ values for June (top) and December (bottom)

## 5. Comparison of effective cloud fraction ( $\left.f_{\text {cld }}^{\text {eff }}\right)$

Here we compare the $f_{c l d}^{\text {eff }}$ values calculated using Eqn 4 above, which is related to optically thick clouds, and those retrieved from a typical set of OMI data. Figure 10 shows that spread in the $f_{\text {cld }}^{\text {eff }}$ values for both sets of meteorological cloud data is
approximately the same. One main difference relates to the frequency of occurrence of low and high values, where the number of smaller $f_{\text {cld }}^{\text {eff }}$ values from the ARPEGE/MOCAGE data exceed those calculated using ECMWF data. This is in spite of the smaller grid cells in the ARPGEGE/MOCAGE data, where there are no instances of $f_{\text {cld }}^{\text {eff }}$ equal to 1.0. When comparing a set of typical values retrieved using OMI data (which are normalised to the total number of values obtained using the meteorological datasets), the frequency of occurrence is rather homogenous across the entire spectrum of values. In essence those from the ECMWF data exhibit a greater similarity than those from the ARPEGE/MOCAGE data. This has the potential to increase large differences in the retrievals when used for assessing the impacts of clouds


Figure 10: As for Figure 9 except for $f_{c l d}^{\text {eff }}$ values. The red plot shows the corresponding values retrieved from a typical set of OMI data.

## 6. Conclusions

1. We have described an approach to convert cloud properties from the meteorological models into effective cloud properties needed to generate the synthetic observations. The input parameters are cloud fraction, cloud liquid water content and cloud ice water content, provided on all model levels. The output parameters are estimates of the optical cloud fraction and optical cloud pressure. For simplicity we have used a maximum overlap approach and a single mean relation between reflectivity and cloud optical depth.
2. Large differences are found between the two meteorological datasets. The ARPEGE model is very humid compared to ECMWF, and the MOCAGE model shows many grid cells with low liquid water contents, in contrast to findings in the literature based on the ARPEGE model alone. This is possibly related to the parameterization contained in the MOCAGE CTM for calculating the LWC from the SH input data from ARPEGE. Another major difference is the extent and distributions of the cloud cover between the two sets of input data, where $100 \%$ cloud cover never occurs for the ARPEGE dataset as found in a previous FP6 EU funded research project related to clouds in meteorological models (see cloud-net.org). Comparing the $P_{\text {clf }}^{\text {eff }}$ values shows that in general ECMWF has the larger cloud fractions located further down in the troposphere for both June and December. When compared to a set values of the effective cloud radiance retrieved using standard OMI data, the ECMWF data exhibits the most homogeneous distribution of values, similar to those retrieved using the OMI data.

These differences are such that they will most likely have a negative effect on the cross-OSSE approach. Either the differences have to be solved, or an alternative approach has to be adopted for the cloud parameters.

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