Radiation Quantities in the ECMWF model and MARS

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This document is correct up to and including cycle 41R1

Abstract

Radiation quantities are frequently required by users of ECMWF data, but there is often confusion about the interpretation of the variables available in the ECMWF Meteorological Archiving System (MARS). This document describes what is presently archived by the operational model, illustrates the various fields obtainable via a MARS retrieval and explains how they should be interpreted.

1 Conventions

The following conventions are employed in the storage of fluxes by the ECMWF model:

1. Archived fluxes are either *downward* or *net*. Energy entering the Earth's atmosphere-surface system is taken as a positive quantity, and therefore downward fluxes are positive and net flux refers to the downward flux minus the upward flux. To obtain the upward flux ($F^{\rm up}$) from the downward flux ($F^{\rm dn}$) and net flux ($F^{\rm net}$), use $F^{\rm up} = F^{\rm dn} - F^{\rm net}$.

2. Physical fluxes archived by the ECMWF model are *accumulated* since the start of the relevant forecast, and therefore in units of J m^{-2} (or W m^{-2} s). Thus, a daily mean (in W m^{-2}) is obtained by retrieving the accumulated fluxes at $t_1 = t$ and $t_2 = t + 24$ hours (where t is the time of the start of the average), taking the difference and dividing by 86400, the number of seconds in a day.

3. *Clear-sky* quantities are computed for exactly the same atmospheric conditions of temperature, humidity, ozone, trace gases and aerosol, but assuming that the clouds are not there.

4. *Solar* or *short-wave* refers to radiation emitted by the Sun, then scattered, absorbed or transmitted by the atmosphere and reflected or absorbed by the surface. It corresponds roughly to the 0.2–4 μm or 50,000–2600 cm^{-1} part of the spectrum. *Thermal, terrestrial* or *long-wave* refers to radiation emitted and absorbed by the surface or by gases, clouds and particles within the atmosphere. It corresponds roughly to the 4–100 μm or 2600–10 cm^{-1} part of the spectrum. Note that there is some spectral overlap between the two, which is fully represented in the model, so the division between solar and thermal radiation should not be thought of as simply radiation with a wavelength shorter or longer than 4 μm, but rather as radiation originating from the sun versus originating from emission by the Earth or its atmosphere.

2 Top-of-atmosphere fluxes

To help explain the surface and top-of-atmosphere (TOA) accumulated fluxes that are archived, Fig. 1 depicts the radiative energy flows in the atmosphere. The fields available at TOA, corresponding to the 0 hPa pressure level, are listed in Table 1, with the symbols corresponding to those shown in Fig. 1.

A frequently required quantity from global models is *Outgoing Long-wave Radiation* (OLR), represented in Fig. 1 by $L^{\rm up}_{\rm TOA}$. The ECMWF model assumes that there is no incoming TOA radiation from any other source than the sun, i.e. $L^{\rm dn}_{\rm TOA} = 0$ (this neglects the 2.73 K cosmic microwave background, which amounts to only 3 μW m^{-2}). Therefore, the net long-wave radiation at TOA (named "TTR" in MARS) is equal to the negative of outgoing long-wave radiation, so OLR $= -$TTR.

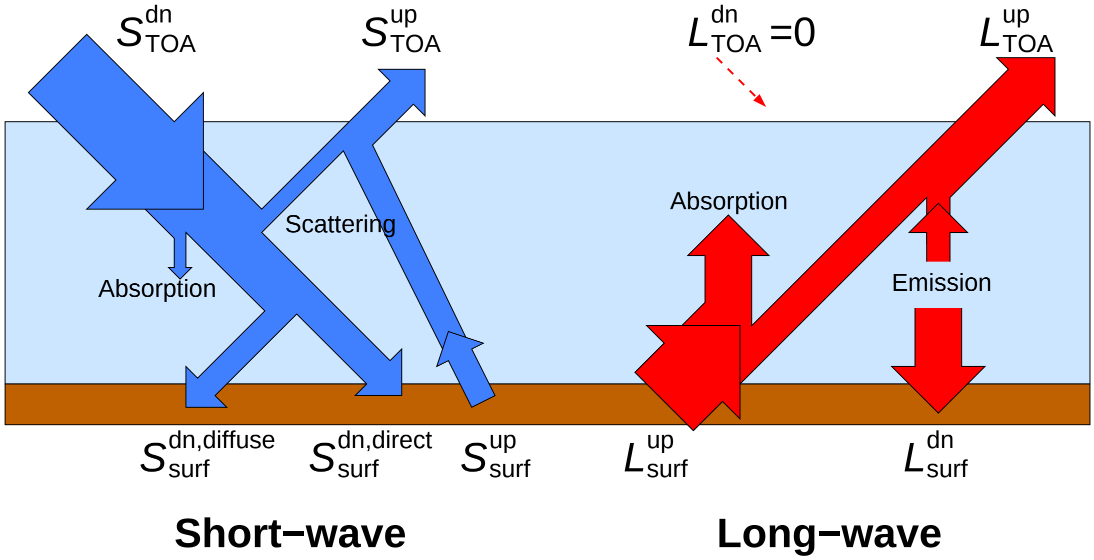

Figure 1: Schematic of the short-wave and long-wave radiative energy flows in the atmosphere. The symbols for upwelling and downwelling fluxes at the top-of-atmosphere (TOA) and surface are used in Tables 1 and 2 to explain what is available from MARS.

Table 1: The fields available from MARS at the top-of-atmosphere (TOA). All are fluxes accumulated since the start of the forecast, in J m^{-2}. The symbols/equations are as shown in Fig. 1. Note that since the small downward long-wave (non-solar) flux from space is neglected (i.e. $L^{dn}_{TOA} = 0$), TTR and TTRC represent the negative of the outgoing longwave radiation L^{up}_{TOA}.

Short Name	Name	Symbol/equation	MARS code
TISR	Top Incident Solar Radiation*	S^{dn}_{TOA}	212.128
TSR	Top net Solar Radiation	$S^{net}_{TOA} = S^{dn}_{TOA} - S^{up}_{TOA}$	178.128
TSRC	Top net Solar Radiation for a Clear-sky atmosphere	$S^{net}_{TOA,clear}$	208.128
TTR	Top net Thermal Radiation	$L^{net}_{TOA} = -L^{up}_{TOA}$	179.128
TTRC	Top net Thermal Radiation for a Clear-sky atmosphere	$L^{net}_{TOA,clear}$	209.128

*Denotes a field available from the reanalysis but not from the operational system.

3 Surface fluxes

The accumulated fluxes available at the surface are shown in Table 2. There are several points to note:

- All quantities are at ground level in the model, according to the model's representation of orography. Some users ask if this is somehow corrected to be the value that would be observed at mean sea level if the Earth had no orography. The answer is no.

- To a reasonably good approximation, SSRD can be considered to be what would be measured by a global pyranometer at the surface, and SSRD – FDIR can be considered to be what would be measured by a diffuse pyranometer. But be aware that the direct (i.e. unscattered) solar radiation in the model actually includes radiation that has been scattered by cloud particles by a fraction of a degree, since the scattering pattern of cloud particles has a narrow peak in the forward direction and it is most efficient and accurate to treat this radiation as if it had not been scattered at all. A further point is that the diffuse downwelling radiation from the model includes diffuse radiation in the direction of the sun, which would be excluded from the radiation measured by a diffuse pyranometer that uses a shadow band to exclude direct radiation. We assume that users who wish to compare direct and diffuse radiation measurements to model output are aware of the correction procedures that should be made to diffuse radiation measurements to account for this effect.

- All fluxes, including direct fluxes, at the surface and top-of-atmosphere represent the energy (in J) that has passed through a square-metre of a *flat horizontal plane* since the start of the forecast. This differs from

Table 2: The surface fluxes accumulated since the start of the forecast that are available from MARS. All are in J m^{-2}. The symbols/equations are as shown in Fig. 1.

Short Name	Name	Symbol/equation	MARS code
SSRD	Surface Solar Radiation Downwards	$S^{\rm dn}_{\rm surf} = S^{\rm dn,direct}_{\rm surf} + S^{\rm dn,diffuse}_{\rm surf}$	169.128
SSR	Surface net Solar Radiation	$S^{\rm net}_{\rm surf} = S^{\rm dn}_{\rm surf} - S^{\rm up}_{\rm surf}$	176.128
SSRC	Surface net Solar Radiation for Clear-skies	$S^{\rm net}_{\rm surf,clear}$	210.128
FDIR	DIRect solar radiation at the surface	$S^{\rm dn,direct}_{\rm surf}$	21.228
CDIR	Clear-sky DIRect solar radiation at the surface	$S^{\rm dn,direct}_{\rm surf,clear}$	22.228
STRD	Surface Thermal Radiation Downwards	$L^{\rm dn}_{\rm surf}$	175.128
STR	Surface net Thermal Radiation	$L^{\rm net}_{\rm surf} = L^{\rm dn}_{\rm surf} - L^{\rm up}_{\rm surf}$	177.128
STRC	Surface net Thermal Radiation for Clear-skies	$L^{\rm net}_{\rm surf,clear}$	211.128

the flux reported by a pyrheliometer pointing directly at the sun, which measures energy into a plane oriented *perpendicular to the incoming unscattered solar radiation*. To convert an instantaneous pyrheliometer flux to the flux into a flat horizontal plane, multiply it by $\cos(\theta_0)$, where θ_0 is the solar zenith angle. Converting direct fluxes in the model to the pyranometer convention is not straightforward since the fluxes are accumulated over a period during which the solar zenith angle changes.

4 Albedo quantities

The albedos available from MARS are listed in Table 3. To interpret them we first discuss briefly how albedo is calculated in the model (valid since model cycle CY32R2). The basic land albedo is calculated from a monthly climatology derived from the MODIS satellite instrument, which has four components: albedos are specified separately for wavelengths shorter than and longer than 0.7 μm, and separately for direct and diffuse radiation. The quantities ALUVP, ALUVD, ALNIP and ALNID in Table 3 are the four components of the land-surface albedo interpolated to the start time of the forecast from the monthly means bracketing this time in the MODIS climatology. They do not include the effects of snow, and are only available at the start of the forecast.

At each timestep within the model, these four albedos are modified to add the contribution from lying snow, which is a dynamic variable in the model. They are then used by the radiation scheme, and the fact that four variables are used means that the total amount of radiation reflected from the surface will depend on cloud cover (which affects the ratio between direct and diffuse surface radiation), trace gas concentrations (which affects the ratio between surface downwelling radiation with wavelengths greater than and less than 0.7 μm) and solar zenith angle (which affects both).

At each timestep an additional instantaneous broadband albedo is computed for diagnostic purposes only, and stored in MARS as “FAL”, as indicated in Table 3. This variable includes the contribution from snow and sea-ice, but is computed as a weighted average of the *diffuse* albedos in the UV-visible and the near-infrared, weighted according to the fixed *top-of-atmosphere* spectral distribution of incoming solar radiation rather than the variable

Table 3: The surface albedo quantities available from MARS. All are non-dimensional and lie in the interval 0–1. The components ALUVP, ALUVD, ALNIP and ALNID are defined at land points only, and are only available in MARS at the start of the forecast.

Short Name	Name	MARS code
ALUVP	UV-visible surface ALbedo for direct (Parallel) radiation	15.128
ALUVD	UV-visible surface ALbedo for Diffuse radiation	16.128
ALNIP	Near-Infrared surface ALbedo for direct (Parallel) radiation	17.128
ALNID	Near-Infrared surface ALbedo for Diffuse radiation	18.128
FAL	Forecast surface ALbedo	243.128

surface spectral distribution. The neglect of the difference between diffuse and direct radiation, and the use of a fixed spectral weighting, means that FAL differs somewhat from the true broadband all-sky albedo in the model, defined as

$$\alpha = S_{\mathrm{surf}}^{\mathrm{up}} / S_{\mathrm{surf}}^{\mathrm{dn}}. \tag{1}$$

Noticeable differences between FAL and α occur particularly over snow and ice where there is a large difference in albedo between the two spectral regions (see Fig. 7).

Users who wish to know α as defined by Eq. 1 are advised to calculate it directly from the archived surface fluxes. From Eq. 1 and the definitions in Table 2, albedo is given by $\alpha = 1 - \mathrm{SSR}/\mathrm{SSRD}$. Since SSR and SSRD are accumulated, this will give the effective albedo averaged over the duration of the forecast up to that point in time. Of course, it will only produce reliable results over points that have been sunlit at some point during the forecast up to that point, i.e. SSRD > 0.

Users who wish to separate the clear-sky surface net shortwave flux, SSRC, into upwelling and downwelling components can do this to a reasonable degree of accuracy using either FAL or α, but should note that neither would reproduce perfectly what was in the clear-sky part of the original radiation calculation. This is because the absence of clouds would lead to a greater fraction of the downwelling surface radiation being direct rather than diffuse, thereby changing the weighting between the direct and diffuse components of albedo.

5 Other variables

Short Name	Name	MARS code
SUND	SUNshine Duration	189.128

Sunshine duration archived from the ECMWF model is defined as the number of seconds since the start of the forecast that the direct downwelling solar flux into a horizontal plane at the surface exceeded 120 W m^{-2}. It is therefore an accumulated field. Unfortunately this differs from the official definition of sunshine duration, which is the same but for direct solar flux *into a plane perpendicular to the sun*. This flux is larger than the flux into a horizontal plane by a factor of $1/\cos(\theta_0)$ (where θ_0 is the solar zenith angle), so the sunshine duration from ECMWF may be underestimated. Therefore it is recommended that this variable is not used.

6 Examples

In the following pages, all radiation fluxes quantities are presented averaged over the first 24-hours of the operational forecast started at 20120215 12 UTC, therefore as averages over the period 20120215 12 UTC to 20120216 12 UTC. The albedo components (Fig. 7) are given at the start of the forecast, 20120215 12 UTC, whereas the surface albedo of Fig. 6 is the value 24 hours into the forecast, thus corresponding to 20120216 12 UTC. Please also note that all albedo components are archived as non-dimensional within the interval 0–1, but are presented in percent in Figures 6 and 7.

Acknowledgements

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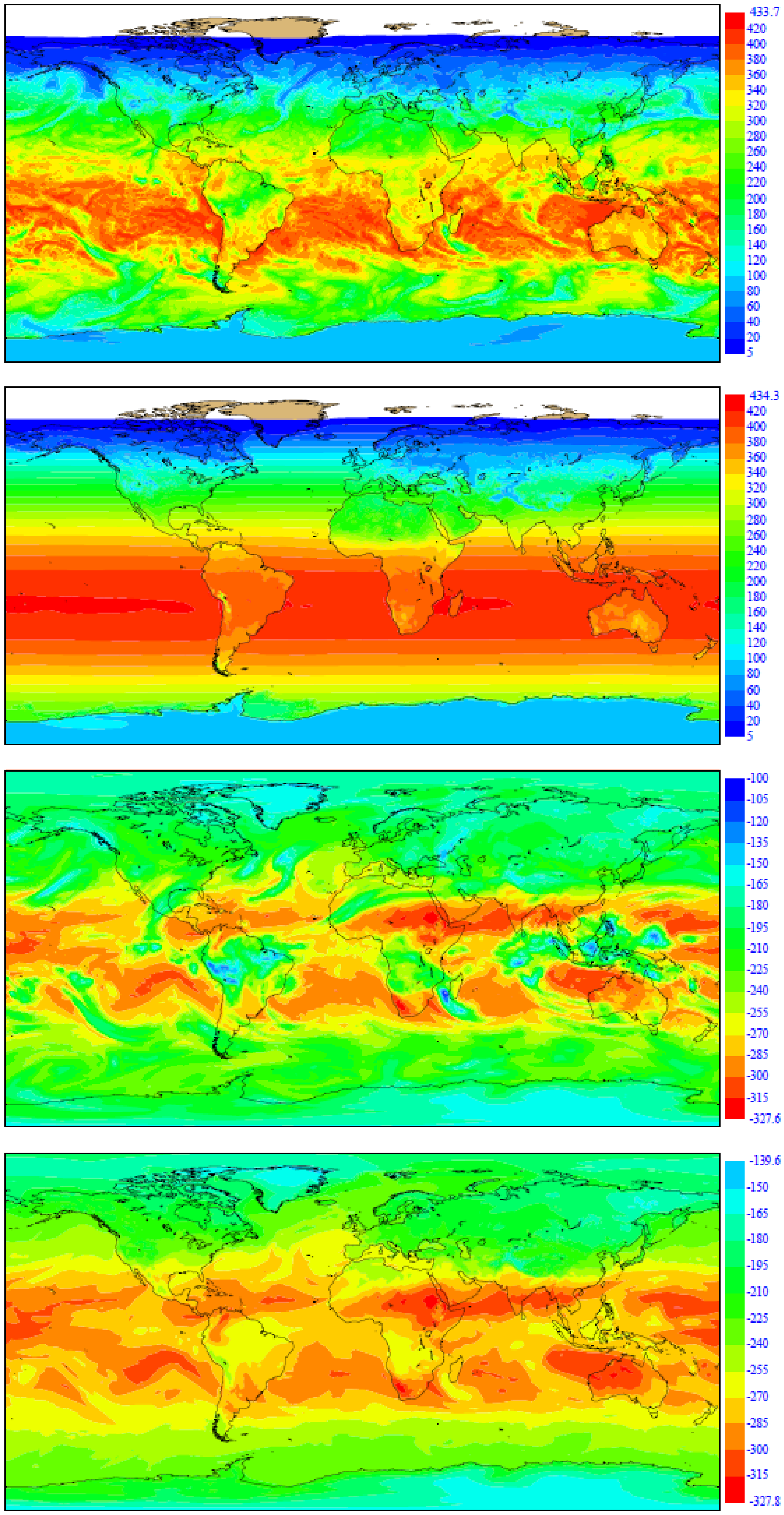

Figure 2: TSR, TSRC, TTR and TTRC averaged over the first 24 hours of the forecast started on 20120215 12 UTC (W m^{-2}).

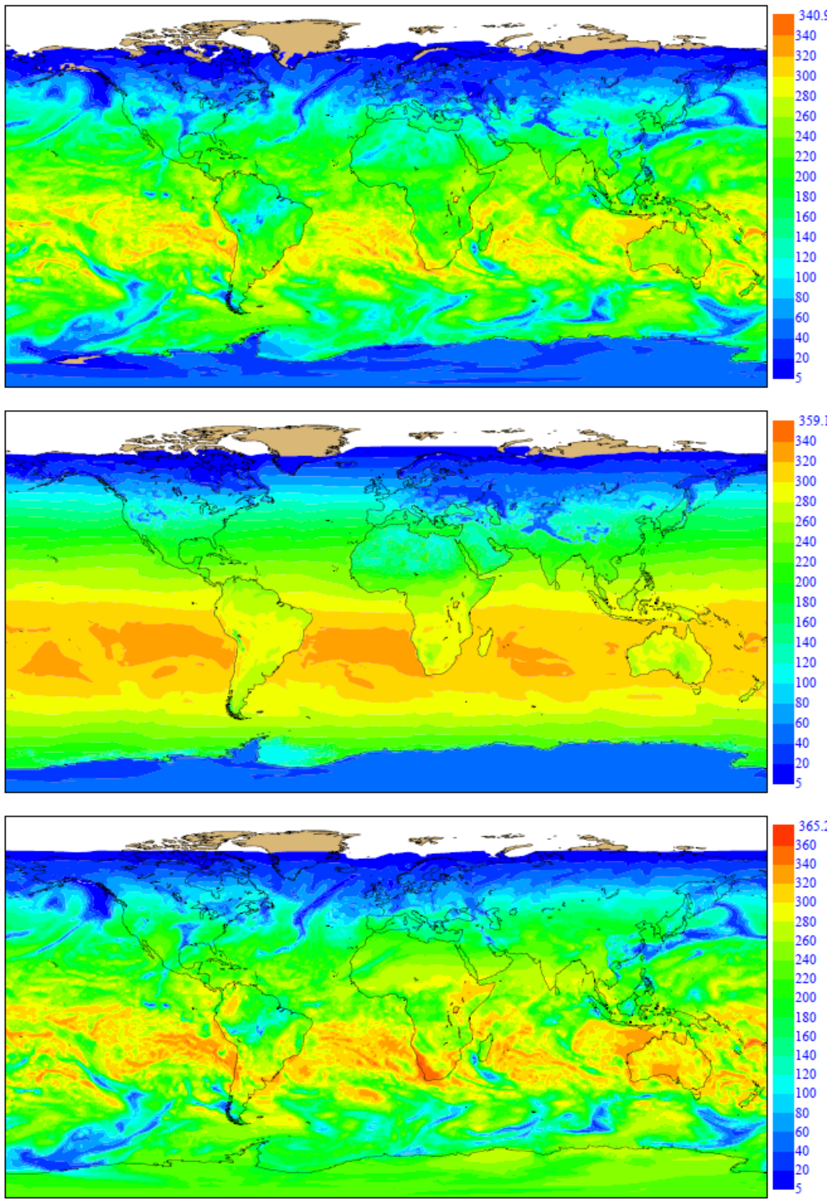

Figure 3: SSR, SSRC and SSRD averaged over the first 24 hours of the forecast started on 20120215 12 UTC (W m^{-2}).

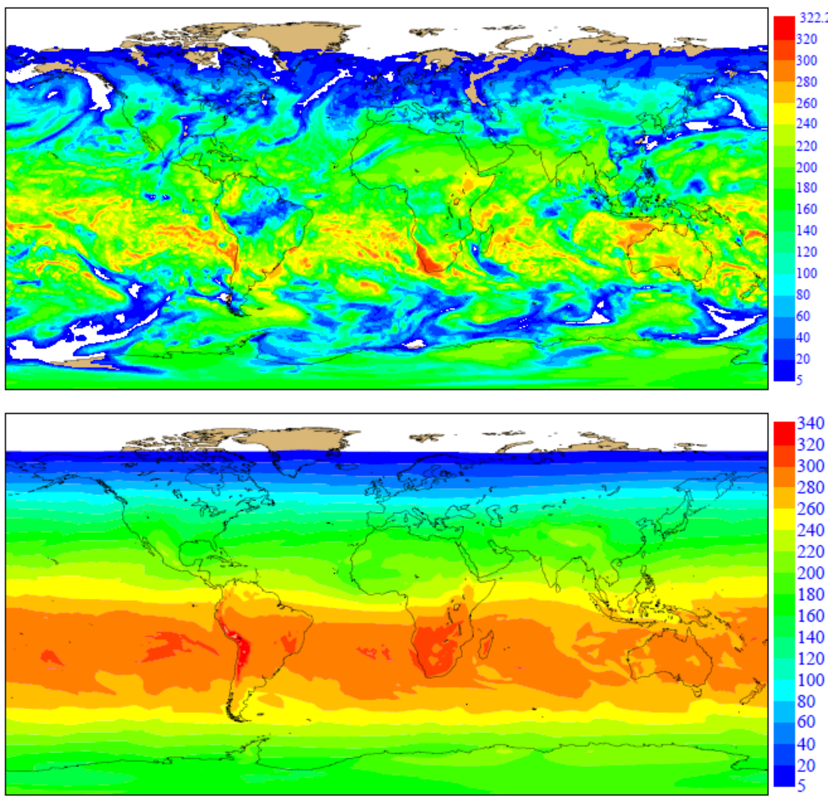

Figure 4: FDIR and CDIR averaged over the first 24 hours of the forecast started on 20120215 12 UTC (W m^{-2}).

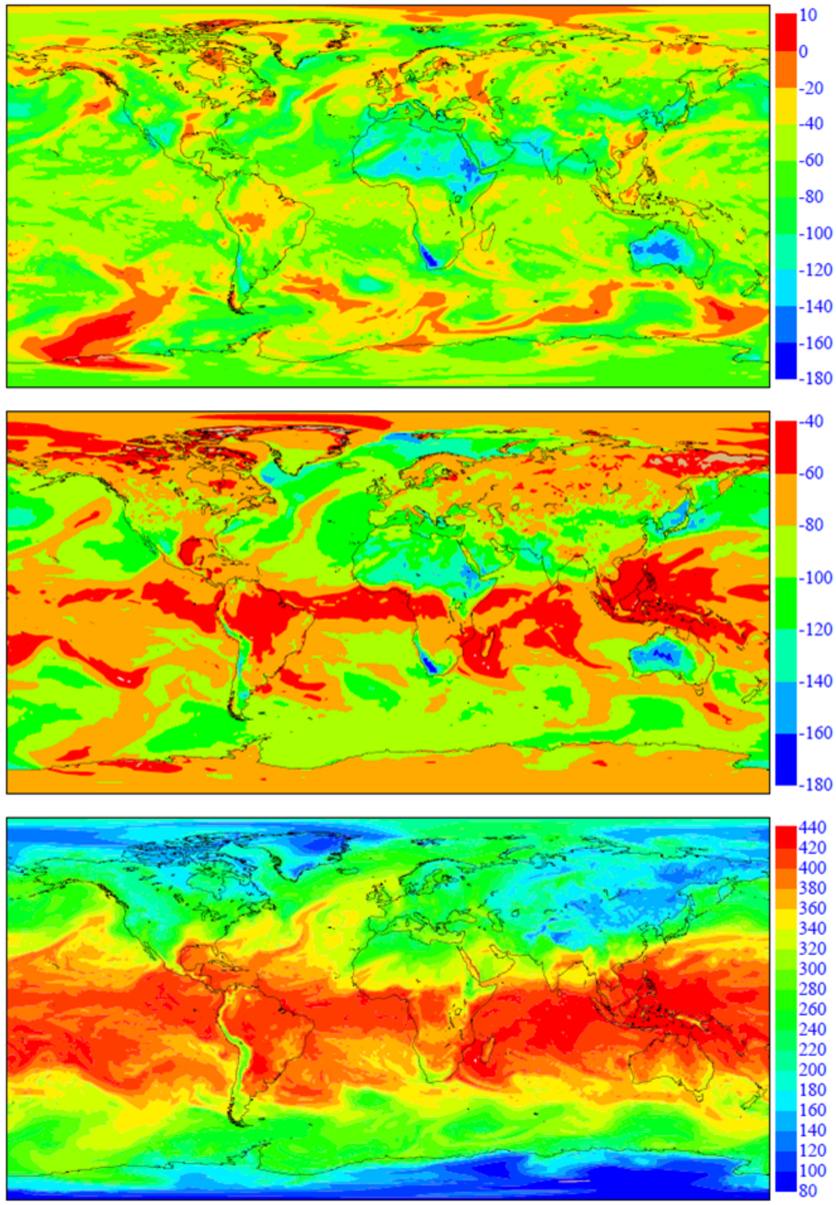

Figure 5: STR, STRC and STRD averaged over the first 24 hours of the forecast started on 20120215 12 UTC (W m^{-2}).

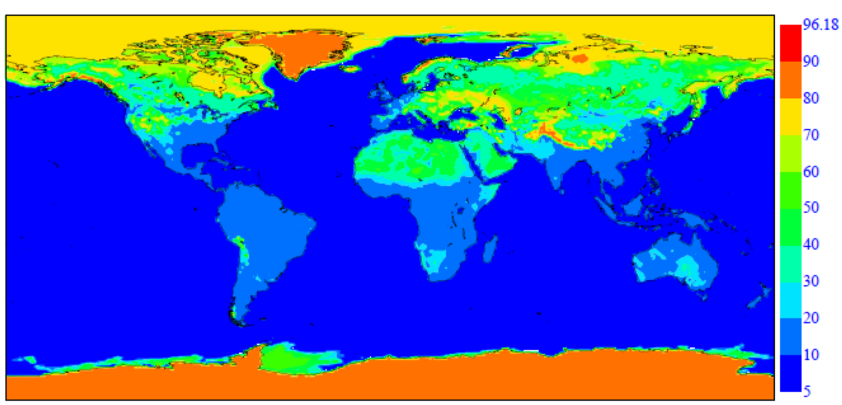

Figure 6: FAL, the forecast albedo, after 24 hours for the forecast started on 20120215 12 UTC (%).

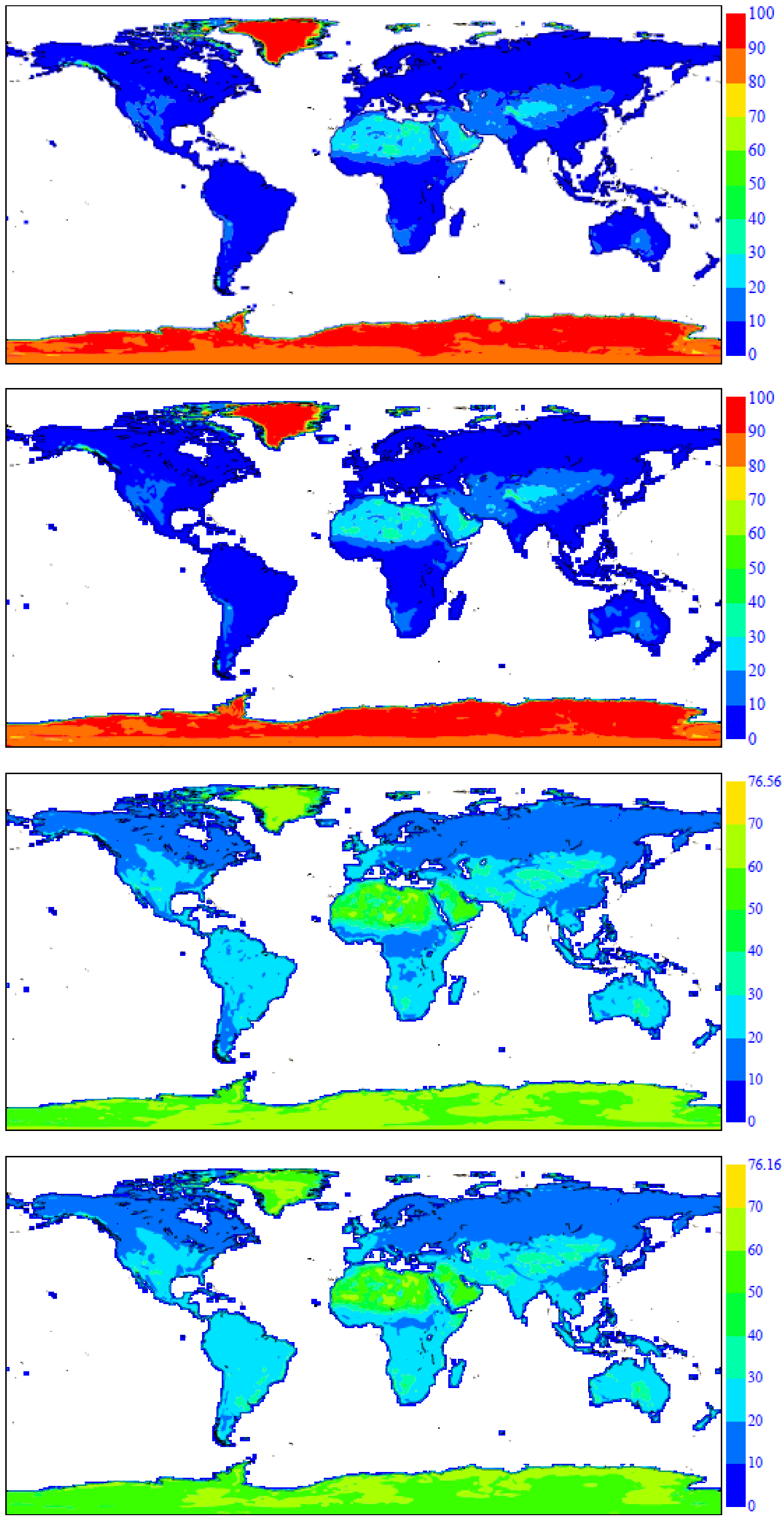

Figure 7: ALUVP, ALUVD, ALNIP and ALNID as used in the forecast started on 20120215 12 UTC (%).