Two Global Data Bases of Photosynthetically Active Radiation

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Abstract

Two global data bases of PAR and solar radiation flux at the surface have been generated by the Science Directorate of Langley Research Centre of NASA and are available to researchers investigating the effects of weather and climate variability on plant growth. One data base is generated as a CERES product and has been demonstrated to have 1% accuracy. These data are available since 2000. Another data base has been developed using operational meteorological satellites and is available from 1983 through 2007. For near-real time applications, the CERES FLASHFLUX provides surface shortwave flux within a week.

1. INTRODUCTION

The sunlight which is used by plants, Photosynthetically Active Radiation (PAR), is the part of the solar spectrum between 0.4 and 0.7 microns, or blue to red. Knowledge of PAR is required for modelling plant growth and productivity. Two global data bases of PAR and solar radiation flux at the surface have been generated by the Science Directorate of Langley Research Centre of NASA and are available to researchers investigating the effects of weather and climate variability on plant growth.

One data base was developed by using data from the Clouds and Earth Radiant Energy System (CERES) and MODIS instruments aboard the Terra and Aqua spacecraft over the period March 2000 to the present. Because of the time required to process the data to the standards required to generate highly accurate results, the standard CERES data products are available at least six months after the measurements are made. For practical applications which require more timely results but need less accuracy, the FLASHFLUX data product for surface solar radiation has been created, but this product does not include PAR at present. Another data base was developed by the Surface Radiation Budget Project in collaboration with the Global Energy and Water Experiment (GEWEX) and uses measurements from operational meteorological satellites. This data base covers the period from July 1983 through December 2009. This paper describes each of these data bases and how to acquire the data. Examples of the PAR data are shown.

Figure 1 shows the spectrum of solar radiation at the "top of the atmosphere" as a blue line. The spectral range of PAR is also indicated. Ozone, other trace gases and aerosols reduce the spectral radiance at the surface. Clouds play a strong role in reducing surface PAR, depending on their optical depth. Thus, accurate computation of PAR demands an accurate value of cloud optical depth. To generate PAR or surface shortwave flux, it is necessary to have data from which the effects of these factors can be computed. The methods by which the CERES and SRB data bases accomplish this are described.

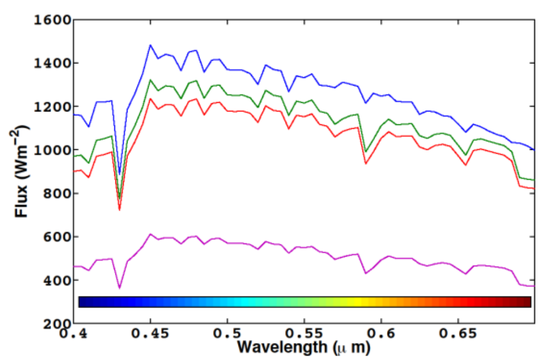

Figure 1: Solar spectrum above the atmosphere (blue line), effects of ozone and trace gases (green line), aerosols (red line), and clouds (red line).

2. CERES OVERVIEW

The CERES project has the objective of measurement the solar radiation reflected from the Earth with an accuracy of 1% and the total radiation, i.e. emitted longwave and reflected solar radiation, with 0.5% accuracy (Barkstrom, 1994; Wielicki et al., 1996). These measurements are used to compute the energy balance of the Earth at the "top of the atmosphere" TOA and the radiation at the surface..

CERES instruments were placed in orbit aboard the Terra spacecraft in December 1999, on the Aqua spacecraft in May 2002 and on the Suomi/NPP satellite in October 2011 (Smith et al., 2014). Terra crosses the Equator at 1030 hours local time and Aqua and Suomi-NPP cross the Equator at 11:30. Thus, these instruments provide measurements twice per day during sunlight.

Each of these spacecraft is an observatory class satellite, carrying a number of instruments for Earth observation. Terra and Aqua each have a MODIS (MODerate resolution Imagmg Spectrometer) and Suomi/NPP has a VIIRS (Visible and Infrared Imaging Radiometer Suite). These instruments supply cloud images in several bands, which are analyzed (Minnis et al., 2010) to give cloud fraction and optical depth. They also supply measurements from which temperature and humidity profiles through the atmosphere are retrieved in another processing stream.

3. CERES PAR DATA BASE

PAR and solar radiation at the surface are retrieved from CERES measurements by use of a radiative transfer code which was developed by Fu and Liou (1992) and modified for use in CERES data analysis by Charlock et al. (2006). The code uses 15 bands of radiation to compute fluxes through the atmosphere. The computed radiances at TOA are constrained to agree with those measured by CERES by adjusting the input parameters within their expected errors (Rose, 2014).

The computation of PAR uses MODIS bands 7 through 10, listed in Table 1. The fluxes in bands 7 and 10 are modified to match the .4 to .7μ range of PAR by use of the SBDART radiation code.

Table 1: Bands used for computing PAR

Band	Range, nm	
7	357.5 – 437.5	Note1
8	437.5 – 497.5	
9	497.5 – 595.5	
10	595.5 – 689.7	Note 2

1. adjusted to 400 – 437.5nm
2 adjusted to 595.5 – 700nm

Aerosol optical depth is also an important parameter and is retrieved from MODIS except when clouds fill more than half of the CERES footprint, in which case aerosol properties from the Model for

Atmospheric Transport and Chemistry (MATCH) are for clear sky other parameters included are solar elevation angle, surface abedo, precipitable water and total column ozone. For cloudy sky, cloud optical depth, height and phase are considered. For many plant types the diffuse PAR is important, so the data base includes total and diffuse PAR.

The measurements and ancillary data are processed to generate PAR and other radiances for each CERES footprint. These quantities are archived as the Single Satellite Footprint (SSF) data set.

The data are next averaged over a 1 degree latitude by 1 degree longitude grid and covers the Earth on a synoptic scale (SYN). Data from operational meteorological satellites are used to help compute PAR for every three hours. Finally, daily means and monthly means are computed and archived. Figure 2 shows an overview of the CERES data processing.

The CERES PAR data base was validated by comparison with measurements from NOAA's SURFRAD network (Su et al., 20??), which has seven sites across the coterminous U. S. Total PAR is measured by a LI-COR quantum sensor, which has an estimated uncertainty of 10%. For all-sky conditions 80% of the CERES PAR measurements are within 10% of the LI-COR results and for clear sky conditions 90% of CERES PAR are within 10% of LI-COR.

The Rotating Shadowband Spectrometer (RSS) is more accurate than the LI-COR, and CERES PAR agrees slightly better with RSS than does LI-COR. The RSS also provides the ratio of direct to diffuse PAR. For a sample of 270 cases, the mean ratio from RSS is 2.6 and from CERES is 1.9. If only clear-sky cases are considered, the comparison is better. The cloudy cases differ largely because CERES makes only one measurement over a 20 km region during an overpass, whereas the RSS measures only over a small area but integrates over a 15 minute period.

PAR and radiation fluxes at the top of the atmosphere and at the surface are available from the CERES data base at

http:\\ceres.larc.nasa.gov/products.php?product=SYN-AVG-ZAVG

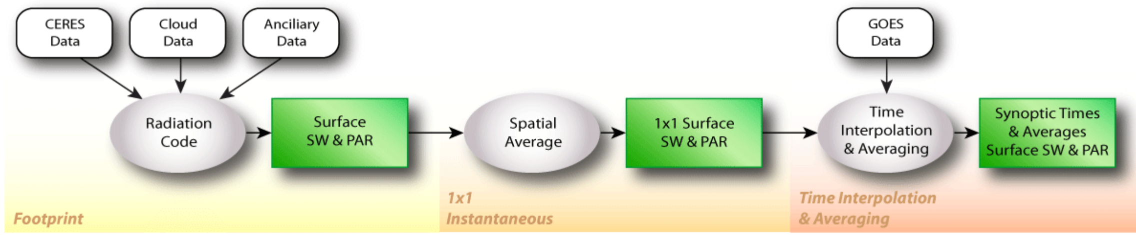

Figure 2: Schematic of Generation of CERES PAR data products

3. EXAMPLES OF USE OF CERES PAR DATA

Some examples are shown here of use of the CERES data base of PAR. Figure 3 is a map of PAR averaged of the day and averaged over all sky conditions for July 2013 for the coterminaous U. S. The effects of clouds is seen over the states east of the Mississipi River and over the eastern Pacific Ocean. The data base also includes the monthly-mean PAR averaged over all clear sky, which figure 4 shows for July 2013. By subtracting the two maps, one finds the effects of clouds on PAR over the coterminous U.S. for July 2013. Figure 5 shows quantitatively the effect of clouds on PAR.

For some plants, e.g. undergrowth in forests, the diffuse part of PAR is of importance. Figure 6 shows the diffuse PAR for all-sky conditions and figure 7 shows diffuse PAR for clear sky..

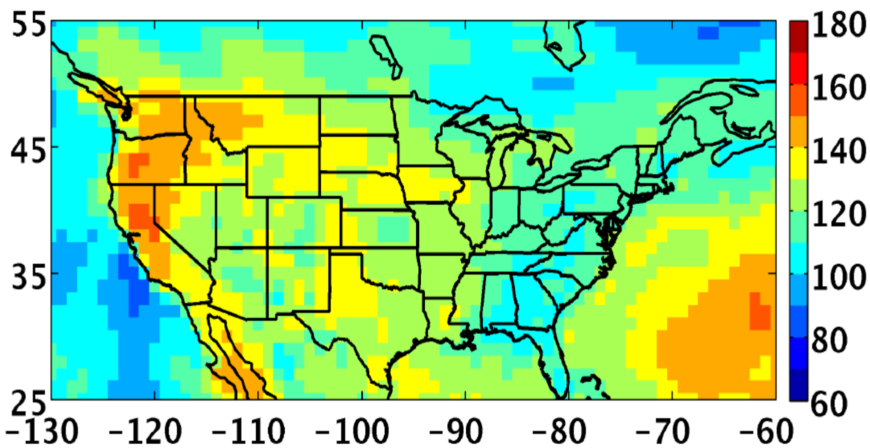

Figure 3: PAR averaged over all sky conditions for July 2013 for coterminous U. S., W m^{-2} .

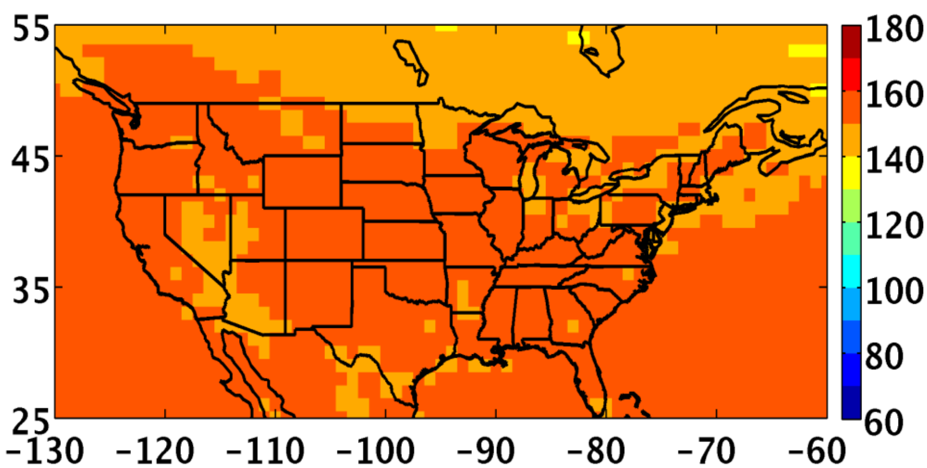

Figure 4: PAR averaged over clear sky conditions for July 2013 for coterminous U. S., W m^{-2} .

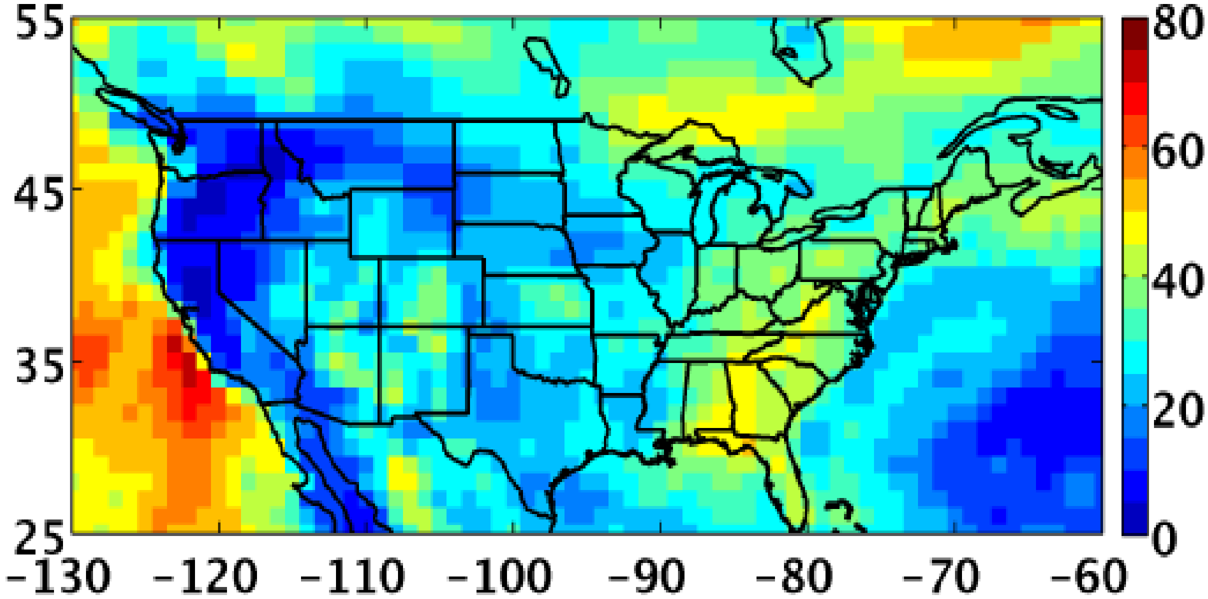

Figure 5: Effect of clouds on PAR for July 2013 for coterminous U. S., W m^{-2}

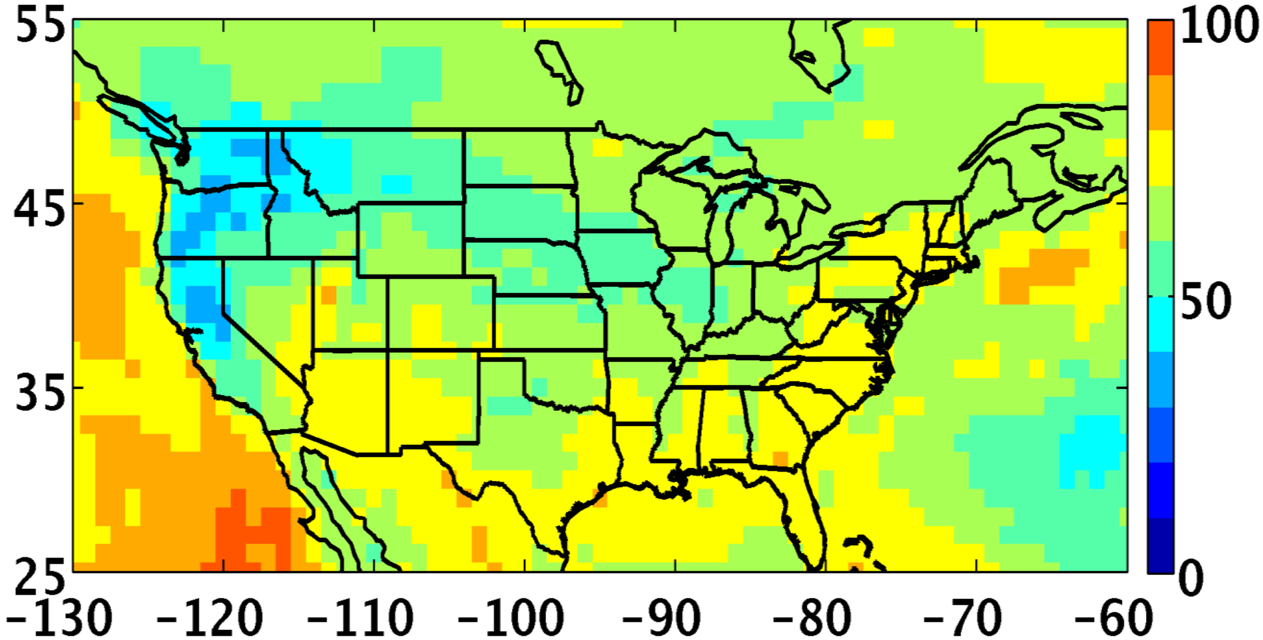

Figure 6: Diffuse PAR under all sky conditions for July 2013 for coterminous U. S., W m^{-2}

For clear sky, the diffuse component of PAR is due to Rayleigh scattering and scattering by aerosols. Figure 7 shows little variation over the area shown. Figure 6 displays large changes over the area due to clouds. The effect of clouds is to increase the diffuse part until the direct beam is small, after which the diffuse PAR would decrease. This decrease due to extreme cloudiness does not appear in the monthly-mean result.

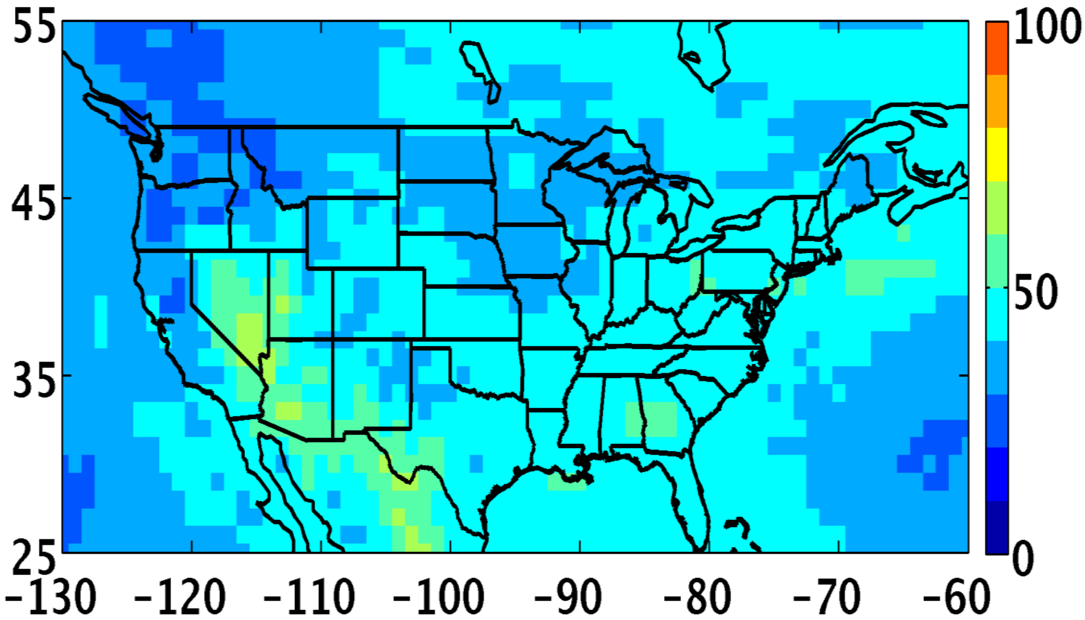

Figure 7: Diffuse PAR clear sky for July 2013 for coterminous U. S., W m^{-2}

4. FLASHFLUX

The main CERES data processing is for production of high accuracy results, which requires over six months before the products can be seen. Because of demand of practical applications of CERES measurements in a shorter time, the FLASHFLUX product (Kratz et al., 2014) has been designed to give the surface shortwave flux in less than a week.

Solar fluxes in FLASHFLUX is computed by the Staylor-Gupta algorithm (Gupta et al., 2001, Kratz et al., 2010) and uses CERES Edition 1 radiances together with atmospheric temperature and humidity profiles and surface temperature from the Global Modeling and Assimilation Office of Goddard Space Flight Center. Figure 8 shows a comparison between FLASHFLUX and measurements from the Baseline Surface Radiation Network. Over a range of 400 W m^{-2} the bias is -6.2 W^{-2} and the standard deviation of the linear fit is 37.6 W m^{-2}. These data are quite good for regions where measurements are not available or where the instruments are not well-maintained or calibrated.

These data for shortwave flux at the surface can be used with empirical relations between the shortwave and PAR to compute PAR for crop forecasting applications.

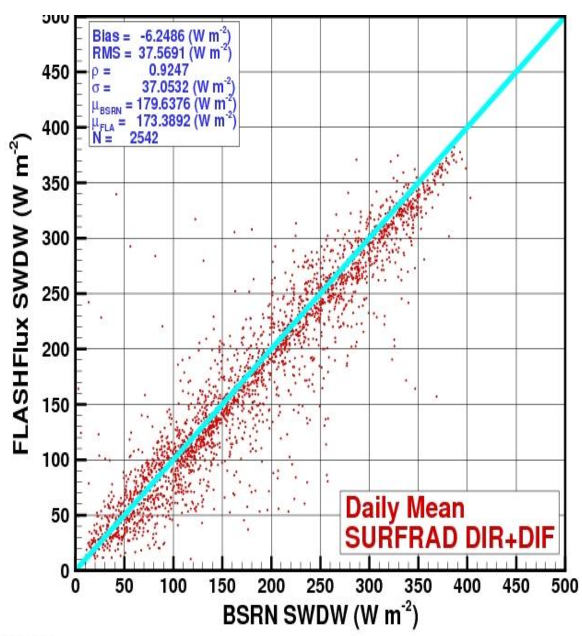

Figure 8: Comparison of FLASHFLUX with Baseline Surface Radiometer Network measurements.

At CSIRO (Commonwealth Scientific and Industrial Research Organiztion, of Australia) FLASHFLUX data are used currently in *APSIM* (The Agricultural Production Systems sIMulator) for crop forecasting in west, east and southern Africa. This program is internationally recognized as a highly advanced simulator of agricultural systems.

The FLASHFLUX surface fluxes can be accessed at

http://flashflux.larc.nasa.gov

5. NASA/GEWEX/SURFACE RADIATION BUDGET DATA SET

The Surface Radiation Budget SRB data set covers the time period of July 1983 through December 2007 (Stackhouse et al. 2011). It uses International Cloud Climatology Project data (Rossow et al., 1999), which are derived from operational meteorological satellite data. The data products include downward and upward surface shortwave and longwave fluxes and PAR for three-hour averages every day, the daily mean and the monthly-mean for regions one degree in latitude and longitude over the globe.

The SRB fluxes have been validated by comparison with SURFRAD. The differences between the daily mean fluxes are less than 1% and the RMS differences are about 15%.

These data are avai

https://eosweb.larc.nasa.gov/project/srb/srb table

Figure 9 is an example of use of the SRB data and shows PAR over Eurasia from 45^{o}E to 125^{o}E and 50^{o}N to 70^{o}N, averaged over July 2006. The effect of clouds east of the Himalayas and of latitude is clear. Figure 10 shows the January 2007 average PAR for this area. The effect of solar declination is clear.

Figures 11 and 12 are Hovmueller diagrams showing the changes over the SRB data period for the PAR averaged over the longitude range 45^{o}E to 125^{o}E of figures 9 and 10. There are fairly large variations during July, which could have had an impact on crops. During January there are variations over the southern part of the range, but the northern part shows very little variation. More research is needed to determine the nature and causes of these variations and the consequences on agriculture and forests across the region.

6.. CONCLUDING REMARKS

This paper has presented examples of PAR data products which have been generated by the CERES and SRB programs. These observations are available at the web sites discussed. These data can be used for research to develop and validate plant growth models. Possible investigations would use plant growth models for reconstructing past crop production to understand effects of weather variations on crop production. For forecasting crop growth, the FlASHFLUX data product is well suited.

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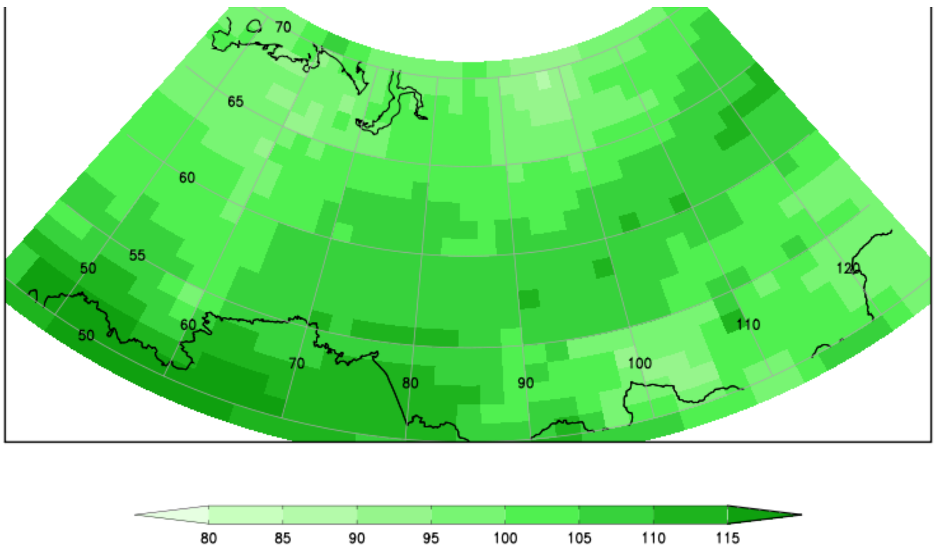

Figure 9: Average PAR for July 2006 over Eurasia. Data from SRB.

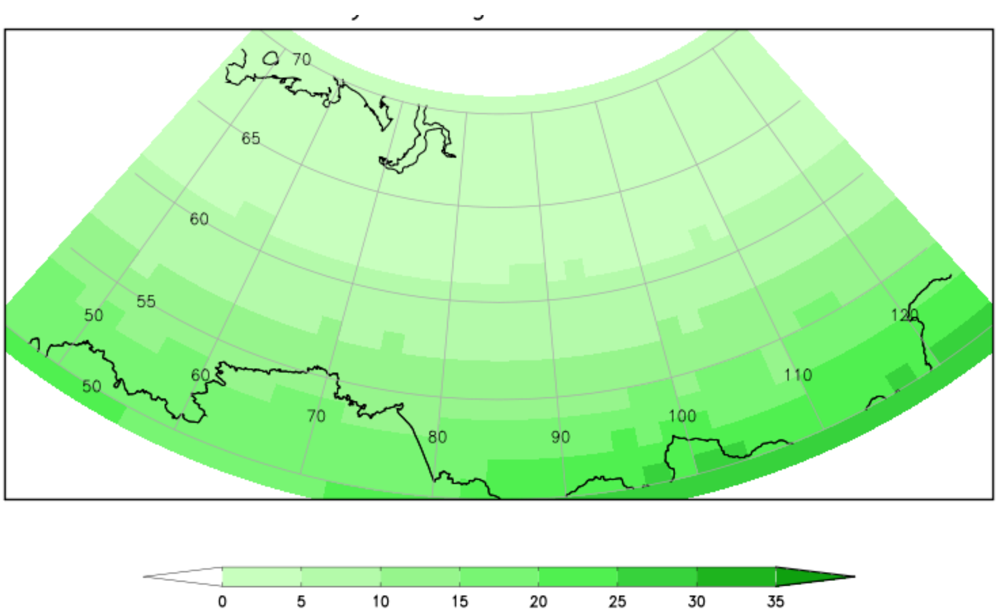

Figure 10: Average PAR for Jan 2006 over Eurasia. Data from SRB.

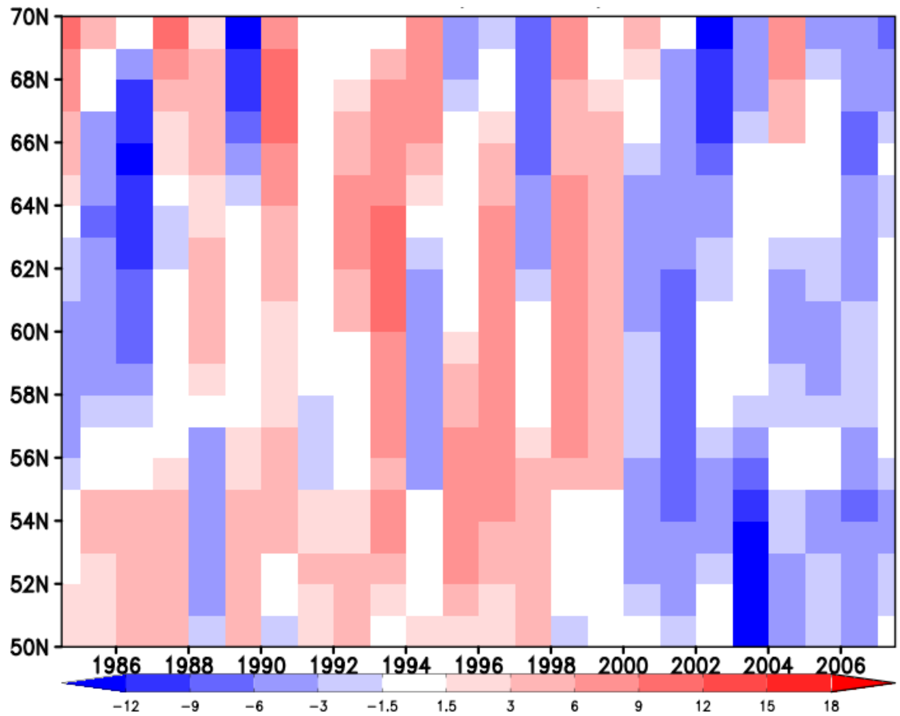

Figure 11: Hovmueller diagram of anomaly of Latitudinal Average 45°E to 125°E of PAR for July.

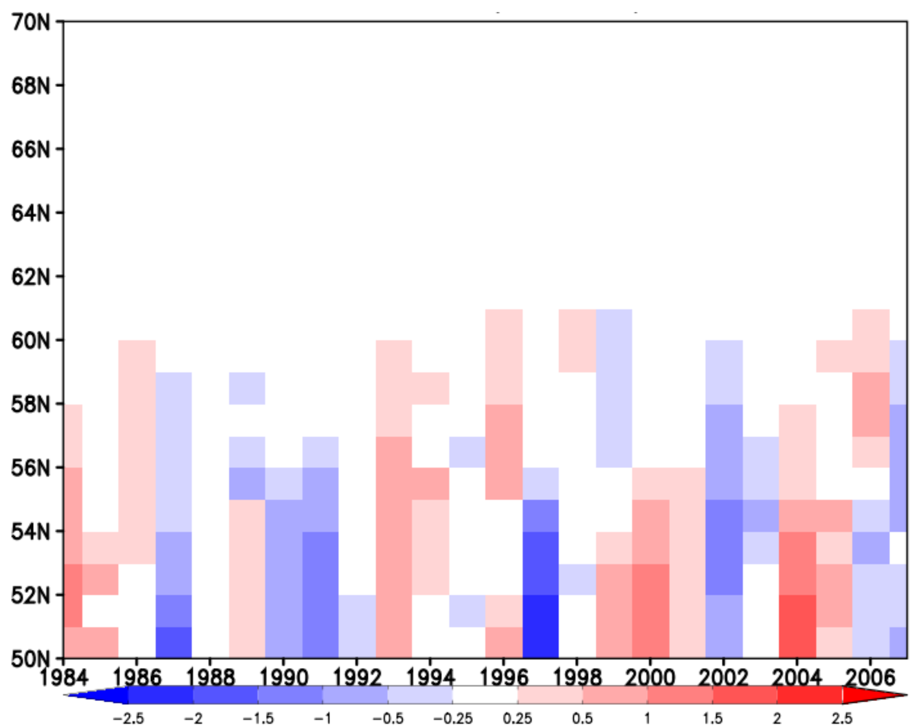

Figure 12: Hovmueller diagram of anomaly of Latitudinal Average 45°E to 125°E of PAR for January.