Existing and planned spaceborne radar missions provide vital cloud and precipitation information over data-sparse oceans and remote land areas. The international community is currently debating how the next generation of spaceborne radars shall enhance current capabilities and address remaining gaps.
References:

Data Sources: The data were used from a variety of sources including NASA ER-2 and DC-8 radars, TRMM, CloudSat, GPM, RainCube. Future missions such as EarthCare and Aerosols Cloud Convection and Precipitation (ACCP), and technology developments (ACERad and WISCR).

Technical Description of Figures:
Top Figure: Although not on the same satellite, existing and planned spaceborne radars cover the detection of all radiatively and hydrologically important clouds (along with complementary information from spaceborne lidar systems). However, several gaps in the detection and characterization of cloud and precipitation conditions remain, especially when our current limitations in multifrequency and Doppler measurements are considered. One of these gaps is for light precipitation, shallow precipitation, snow, drizzle, etc. that is covered well by the Ka/W frequency pair and that is being considered by ACCP. This gap assumes that GPM is flying and the EarthCare W band satellite has launched.

Bottom Figure: An overview of the radar band and multifrequency “availability” in the case study of a vertical cross section through a tropical maritime organized convection for a Ku/Ka/W system using radar characteristics that would be typical in future missions. The signal from all three bands is typically available (dark gray color), except for the thin cirrus clouds and the heavy precipitating cell. The W and Ka bands are highlighted here since they align with ACCP. Most notable is that no single frequency covers all the precipitation types. Ku band and lower frequencies are needed for the convective regions, and W band is required for the more tenuous cloud top cirrus. Both the lower and higher frequencies overlap to some extent, but the higher frequencies suffer from Mie scattering and attenuation that can make them less quantitatively useful.

Scientific significance, societal relevance, and relationships to future missions: Current knowledge of clouds and precipitation has highly benefitted from past (TRMM) and present spaceborne based radar missions (GPM, CloudSat, and RainCube) but important gaps still remain for a thorough understanding of the water cycle and its evolution in a warming climate. Spaceborne radars are a critical part of the cloud and precipitation remote sensing observing system; however, apart from the long-waited EarthCARE radar, the next generation of cloud and precipitation radar systems is still under consideration. NASA Decadal Survey activities for the combined Designated ACCP observables have provided significant technology development needed for the next generation of spaceborne radars. The NASA activities have brought together the international radar community to identify key scientific questions, to define associated science requirements, to enable technical and cost-effective solutions to address them, and to seeking support by coordinating funding at the national and international level.
EPIC’s unique position at the Lagrange point L1 between the Sun and the Earth (1.5 million km from Earth) makes observations of the daytime variability in cloud fraction on the sunlit side of the Earth possible. Over ocean, cloud fraction shows a minimum at noon, increasing early morning and late afternoon. In contrast, there is no discernible daytime pattern over land, with cloud fraction evolution depending strongly on latitude. Regionally, EPIC confirms the known cycles of marine stratocumulus and convection.
Reference:

Data Sources: NASA DSCOVR EPIC Level 2 – Cloud products Version 1, available at the NASA's Atmospheric Science Data Center (ASDC): [https://eosweb.larc.nasa.gov/project/dscovr/dscovr_epic_l2_cloud_01](https://eosweb.larc.nasa.gov/project/dscovr/dscovr_epic_l2_cloud_01)

Technical Description of Figures:
*Right panels:* Annual zonal cloud fraction variability over oceans (top) and land (bottom) at four local day times, along with the daily average (black line). The cloud fraction for each time of the day is plotted with a different color. Those latitudes with dotted lines are considered non statistically significant due to a low pixel count. *Left image:* An example EPIC image where we overlay with the same colors used in the right panels the Earth segments corresponding to the local times under investigation. Polar orbiting satellites capture the earth at a specific time of the day for most latitudes, missing strong regional cloudiness variations. The annual analysis distinguishes between ocean and land to emphasize the differences in their daytime variability. Our paper also investigates viewing zenith angle dependences in order to discern between real cloud fraction variability and retrieval algorithm artifacts.

Scientific significance, societal relevance, and relationships to future missions: Cloud cover is one of the main factors determining the Earth energy balance. However, up to date, analyses of its diurnal (daytime) changes at *global scales* was only available from ISCCP or General Circulation Models, which provided contrasting results in many situations. Currently, direct observations of daytime cloud variability on a global scale are only possible with the EPIC instrument ([epic.gsfc.nasa.gov](http://epic.gsfc.nasa.gov)) of the DSCOVR satellite due to its unique location. This work will potentially be useful for assessing cloudiness in current and future GCMs and for a more in-depth understanding of the importance of daytime cloud cover variability in a changing climate. Furthermore, these findings underscore the importance of the L1 vantage point for the Earth sciences research.
A perception has emerged that satellite-based reflectances are limited in terms of their ability to predict gross primary production (GPP) globally at weekly temporal scales.

Our results show that MODIS reflectances, when paired only with potential short-wave radiation, capture a large fraction of GPP variability (~77%) at daily to weekly time scales.

Our estimated global annual mean GPP for 2007, 142.5 ± 7.7 Pg C yr, is higher than some other satellite-based estimates but within the range of other reported observation-, model-, and hybrid-based values.

We have released a new state-of-the-art 20 year MODIS-based GPP data set, designed for benchmarking models used for future predictions.

Data Sources:
Satellite-derived gross primary productivity (GPP) estimates are based on the MCD43 Nadir Bi-directional Reflectance Distribution Function (BRDF) Adjusted Reflectances (NBAR) from the Aqua and Terra MODerate-resolution Imaging Spectroradiometer (MODIS) and tower-based eddy covariance GPP estimates from the Fluxnet 2015 network of sites.

Technical Description of Figure: The figure shows the flow of data used in training and evaluating machine learning based GPP models and their uncertainties through upscaling of FLUXNET 2015 data. The map on the left shows annual mean gridded GPP for 2007 derived with our approach and on the right the corresponding GPP annual mean uncertainties. Our values are higher than other satellite-based estimates, particularly in the tropics presumably because our approach implicitly accounts for the fact that plants are more productive in cloudy conditions and most other approaches do not. We found that the meteorological data added little value to our GPP estimates that effectively use only satellite data. Machine learning optimizes the use of the information content in the satellite reflectances. We found that the use of other popular vegetation indices reduces the information content in compression of many bands into a single parameter.

Scientific significance, societal relevance, and relationships to future missions:
Gross primary production (GPP), the amount of carbon dioxide (CO$_2$) that is assimilated by plants through photosynthesis, is one of the most variable and uncertain components of the global carbon cycle. Dynamic global vegetation models, driven by observed environmental changes, are used for global carbon budget assessments. Benchmarking these models globally with data-driven GPP estimates is critical for understanding the land sink. A general conclusion of our work is that data quality and processing techniques play a substantial role and can affect interpretation of the satellite data and its effectiveness for estimating GPP.

Our results will be applicable to the upcoming NASA Plankton, Aerosol, Cloud and ocean Ecosystem (PACE) mission and the geostationary Earth Ventures Tropospheric Emissions: Monitoring of Pollution (TEMPO) mission as well as decadal survey Surface Biology and Geology (SBG) mission. In addition, our MODIS product may be continued (before launch of these new instruments) with the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument flying on NOAA operational satellites.