

## CloudyRadiances

Assimilation of cloud-affected radiances in the regional weather model AROME

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### Projektbeschreibung

Die Genauigkeit von numerischen Wettermodellen bzw. die der damit generierten Vorhersagen ist in einem hohen Maße von den Beobachtungsdaten abhängig die in den atmosphärischen Ausgangszustand der Modellrechnung eingehen. Daten von Satelliten spielen hier schon seit vielen Jahren eine bedeutende Rolle und haben mitgeholfen die Vorhersagegüte in den letzten Jahren signifikant zu erhöhen.

Allerdings wird derzeit nur ein Bruchteil (ca. 5-10%) der verfügbaren Satellitendaten genutzt, da nur Daten bzw. Radianzen aus wolkenfreien Regionen assimiliert werden. In der Regel sind es jedoch gerade die bewölkten Regionen, die eine größere Herausforderung für die Wettermodelle darstellen. Daher haben gerade Daten für diese Regionen entsprechendes Potential weitere signifikante Verbesserungen bringen zu können.

Eine Verwertung der Radianzen aus bewölkten Gebieten, sogenannte "cloud-affected radiances" (oder kurz "cloudy radiances"), bringt einige Schwierigkeiten mit sich. International betrachtet werden "cloudy radiances" erst vereinzelt in operationellen Wettermodellen assimiliert und dabei meist nur Kanäle im infraroten und nicht im visuellen Bereich oder in Kombination. Für Regionalmodelle bzw. speziell für den Alpenraum sind keine operationellen Anwendungen bekannt. Im Projekt CloudyRadiances setzen sich die Projektpartner ZAMG (Zentralanstalt für Meteorologie und Geodynamik) und IMGW (Institut für Meteorologie und Geophysik der Universität Wien) daher das Ziel, erstmals bewölkte Radianzen in einem konvektionsauflösendem Regionalmodell (AROME) einzusetzen und dabei sogar noch einen Schritt weiterzugehen: Nicht nur der Infrarotbereich soll genutzt werden, sondern auch Kanäle im sichtbaren Spektralbereich. Gerade Letzteres scheint im Hinblick auf die Vorhersage von beispielsweise Konvektion im Sommer oder Hochnebel und Nebel im Winter entsprechendes Verbesserungspotential mit sich zu bringen.

Um den Einfluss dieser Daten auf die Vorhersagequalität quantifizieren zu können sind im Projekt zunächst eine Reihe von technischen und methodischen Entwicklungen im AROME Modell notwendig. Gleichzeitig müssen auch die derzeit verfügbaren Operatoren, die für die Übersetzung von Beobachtungs- in Modellgrößen (und umgekehrt) zuständig sind implementiert und für die speziellen topographischen Gegebenheiten des Alpenraums angepasst werden. Ob eine Assimilation der erweiterten Satellitendaten letztendlich zu Verbesserungen der Vorhersagequalität führen kann, werden ausgiebige Tests zeigen.

Die angestrebten Ergebnisse und Entwicklungen des Projekts sind für die internationale Modellentwickler-Community (z.B. ACCORD Konsortium) von hohem Interesse und werden entsprechend disseminiert.

## Abstract

The accuracy of numerical weather prediction models and forecasts is to a great extent depending on the observation data which is used to create the atmospheric initial conditions for the model run. Satellite data have played an important role for many years already and have contributed to significant improvements in forecast quality.

However, just a small fraction of the overall available satellite data is used nowadays (5-10%). The reason for that is that only radiances from cloud-free areas are usually assimilated into weather models at the moment. But in practise, the cloudy areas tend to be sensitive for the development of certain weather phenomena which are in particular challenging to predict. That is why data from these regions have a high potential to bring significant improvements accordingly.

Exploiting satellite radiances in numerical weather prediction models from cloudy regions, so-called cloud-affected radiances (or cloudy radiances), is a challenging task. Only a few global operational models worldwide assimilate cloud-affected radiances at the moment, and if they do so, just infrared channels are used, but no visible channels or even a combination of both. An application in regional weather models, in particular for the Alpine region, is not known.

Within the project CloudyRadiances the project partners ZAMG (Zentralanstalt für Meteorologie und Geodynamik) and IMGW (Institut für Meteorologie und Geophysik, University Vienna) thus formulate the target to assimilate cloudy radiances in a convection-permitting regional model (AROME) for the first time and even go beyond that: In addition to infrared channels also visible channels will be used and exploited. The latter in particular has the potential to improve the forecast accuracy for summertime convection, fog or low stratus during wintertime.

Several technical and methodical developments within the AROME model have to be completed to evaluate the impact of this data on the forecast. Available operators for translating observational variables into model variables (and vice versa) have to be implemented and modified to cope with the topographical conditions in the Alpine region. Extensive tests will finally prove whether an extended usage of satellite observations will result in improved forecast quality.

Project results and deliverables will be of high interest for the international community of model developers (e.g., ACCORD consortium) and will be disseminated accordingly.

## Endberichtkurzfassung

CloudyRadiances was carried out by the project partners GeoSphere Austria and the Department of Meteorology and Geophysics of the University of Vienna (IMGW) with the goal of improving high-resolution weather forecasts by enabling the use of satellite observations from cloudy regions ("cloud-affected radiances")—conditions under which current data assimilation systems typically discard a large portion of the available observations. The project focused on integrating so-called "All-Sky" radiances—i.e., radiance measurements from both cloudy and cloud-free areas of the Meteosat Second Generation (MSG) satellite's instrument SEVIRI into the AROME weather model used operationally at GeoSphere Austria. Particular attention was given to two water-vapor channels in the infrared spectral range as well as one visible channel. The underlying scientific motivation is that radiances originating from cloudy regions provide valuable additional information on atmospheric moisture and cloud structures within active weather systems, information that is crucial for improving analysis and forecast quality.

Over the course of three years, the project developed the technical and scientific foundations necessary for All-Sky radiance assimilation. This included extending the radiative transfer model RTTOV (Radiative Transfer for TOVS) to handle cloud-affected observations, adapting the AROME observation data flow, and implementing a cloud-dependent observation-error model. In addition, an extended control vector was introduced that incorporates cloud liquid water and cloud ice, allowing the model to adjust cloud processes more directly and physically consistently to satellite observations—beyond the previous

indirect correction via specific humidity alone.

A key scientific focus was the analysis and correction of systematic differences between observed (satellite) and simulated (model) radiance fields. This involved studies of surface albedo, topographic effects, and radiative-transfer characteristics under varying cloud and solar-illumination conditions. Furthermore, the project identified fundamental deficiencies in the currently used RTTOV version for visible channels, necessitating the use of newer operator versions for future assimilation experiments.

The central success of CloudyRadiances lies in the successful assimilation of cloud-affected infrared radiances. Extensive tests and comparisons with reference model runs without All-Sky radiances demonstrated the substantial potential for improving cloud and precipitation forecasts. In particular, the spatial structure of precipitation events and the development of summertime convection can be represented more realistically, results that strongly support future operational use of the project outcomes within GeoSphere Austria.

Although a fully cycled assimilation experiment for visible channels could not be completed due to current limitations in RTTOV, the complete technical infrastructure required for such experiments was established. The project therefore provides a solid foundation for future All-Sky data assimilation and valuable impulses for the international research community working on numerical weather prediction.

CloudyRadiances is ultimately also a strong example of a successful collaboration between a University Institute and a National meteorological service with operational responsibilities. The close integration of scientific expertise from IMGW and operational experience from GeoSphere Austria demonstrates how joint research can contribute to further improvements of key weather-forecasting systems.

### **Projektkoordinator**

- GeoSphere Austria - Bundesanstalt für Geologie, Geophysik, Klimatologie und Meteorologie

### **Projektpartner**

- Universität Wien