The use of satellite data assimilation methods in regional NWP for solar irradiance forecasting

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[1]UMR 288 ESPACE-DEV, Université de La Réunion, France, [2]Reuniwatt SAS, France, [3]UMR 8105 Laboratoire de l'Atmosphère et des Cyclones (LACy), Université de La Réunion, France, [4]UMR 288 ESPACE-DEV, Université de Guyane, France, [5]University of Reading, UK

1. Motivation

Photovoltaic energy offers an intermittent production. PV production forecasts are necessary to permit a safe integration into the electricity grids. The correct simulation of cloud evolution is essential to forecast accurately irradiance reaching the ground level. Besides solar power forecasting, accurate short-term forecasts of precipitating and non-precipitating clouds are important for various meteorological applications. Regional NWP is the state-of-the-art tool to provide highly resolved cloud forecasts for lead times beyond 6h. Clouds are currently rather poorly represented in NWP models. The precise simulation of cloud evolution requires accurate atmospheric analyses which are obtained by exploiting atmospheric observations using data assimilation methods. In this work we focus on the assimilation of geostationary satellite data into regional NWP models with the goal of improving short-term cloudiness forecasts at high spatial resolutions.

2. Advantages of satellite observations

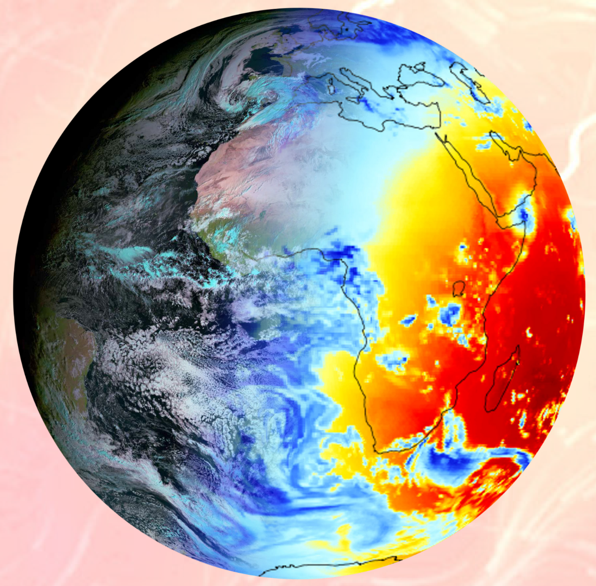

Figure 1: Mashup of a MSG-2 RGB composite (source: EUMETSAT) and a GFS GHI forecast (visualised using Panoply).

Compared to other sources of observations, geostationary satellites provide many advantages regarding continuous solar irradiance forecasting:

- large spatial coverage ; high spatial and temporal resolution
- lack of measured data around islands
- satellite radiances are reliable radiometric signatures of cloud presence, properties and evolution
- constant accuracy in space and time
- comprehensive observations for large parts of the world
- future-oriented

3. Indirectly influencing cloud evolution

In common state-of-the-art data assimilation procedures, primarily applied to global NWP models, all types of available observations are assimilated using the established methods (e.g. 3D-Var, 4D-Var, ENKF). The ultimate goal is to find the optimal initial conditions regarding the model's state variables. The typically assimilated satellite observations are radiances and atmospheric motion vectors (AMVs). Assimilating such observations using variational data assimilation or Ensemble Kalman Filter methods affects the model state variables in the first place and therefore influences the representation and evolution of clouds indirectly.

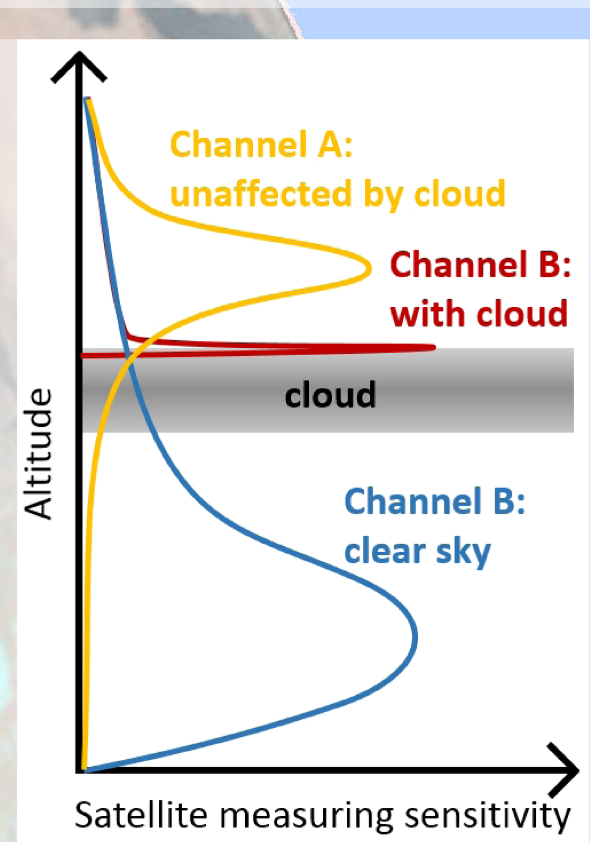

Figure 2: Sketches of arbitrary satellite IR weighting functions for different cases. (After lecture notes of Tony McNally (ECMWF))

4. Recent developments and their shortcomings

In the recent years, different approaches aimed at deriving atmospheric analyses for limited-area models with most realistic cloud features, using geostationary satellite observations. The focus is mostly set on the assimilation of cloud-top information (e.g. cloud top temperature), since optical and thermal sensors are not able to capture information inside clouds (Figure 2).

Table 1 sums up recent advances and their main limitations. Although the listed methods generally provide improved intraday (and even day-ahead) cloud cover forecasts in mid-latitudes, a major limitation for all methods is that only clear-sky or completely cloudy cases can be considered. This is because fractional clouds cause a measured signal mixing cold clouds and the warmer Earth surface.

Satellite-derived parameters	Influenced model variables	Assimilation method	Applied regional NWP model	Satellite sensors	Main limitation of the procedure	Reference
Cloud mask, cloud classification, cloud top height	Relative humidity, cloud-top height, cloud fractions	Assimilation of pseudo-observations using a LETKF	COSMO	MSG-SEVIRI	Method requires radiosonde humidity soundings	Schomburg et al. (2014)
Cloud mask, cloud-top temperature	Water vapour profile	Direct modification of model fields (water vapour profile)	WRF	GOES-N Imager	Modified model fields have to be smoothed horizontally and vertically to avoid numerical instability	Mathiesen et al. (2013)
Cloud-top temperature and pressure by OCA (Optimal Cloud Analysis product)	Water vapour profile	Direct modification of model fields (water vapour profile)	WRF	MSG-SEVIRI	Multi-layered cloud structures cannot be reconstructed in the model	Schipper and Mathiesen (2015)
Cloud-top temperature and cloud albedo	Vertical velocity and divergence	1-D Var for horizontal wind, nudging of model winds	WRF	GOES-N Imager	Method triggers dissipation/creation of model clouds but not their vertical extent and structure	Pour Biazar et al. (2011)

5. Outline

Progress being made regarding the assimilation of cloud-affected radiances into limited-area NWP models (Stengel et al., 2013). However, the indirect assimilation of quantities like radiances or AMVs has not been exploited so far in regional NWP regarding solar irradiance forecasting. The main reason for this is a number of problems that have to be overcome for each individual model domain: the choice of satellite channels, optimal thinning, bias correction, observation and background error estimation.

Future investigations address:

- the combination of both the classical "indirect" assimilation methods with methods that explicitly assimilate cloud physical properties (e.g. cloud top height, cloud emissivity, …).
- the impact of such methods on different lead times, since the information from the driving global model is expected to predominate at a certain point.
- the influence of domain size and grid spacing in connection with satellite data assimilation in regional NWP.
- the use of different limited-area models and satellites, and respectively the application to different geographical regions (e.g. mid-latitudes and tropics).

The ultimate goal is an assimilation strategy that can be used independently of the model and satellite and which can

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ESPACE DEV — Reuniwatt — LACy UMR 8105 — University of Reading