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Crop growth modelling and crop yield forecasting using satellite-derived meteorological inputs

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Abstract

Distributed crop simulation models are typically confronted with considerable uncertainty in weather variables. In this paper the use of MeteoSat-derived meteorological products to replace weather variables interpolated from weather stations (temperature, reference evapotranspiration and radiation) is explored. Simulations for winter-wheat were carried for Spain, Poland and Belgium using both interpolated and MeteoSat-derived weather variables. The results were spatially aggregated to national and regional level and were evaluated by comparing the simulation results of both approaches and by assessing the relationships with crop yield statistics over the periods 1995–2003 from EUROSTAT. The results indicate that potential crop yield can be simulated well using MeteoSat-derived meteorological variables, but that water-stress hardly occurs in the water-limited simulations. This is caused by a difference in reference evapotranspiration which was 20–30% smaller in case of MeteoSat. As a result, the simulations using MeteoSat-derived meteorological variables performed considerably poorer in a regression analyses with crop yield statistics on national and regional level. Our results indicate that a recalibration of the model parameters is necessary before the MeteoSat-derived meteorological variables can be used operationally in the system.

Keywords: Crop growth model; MeteoSat; Yield forecasting; Regional level

1. Introduction

Agrometeorological crop simulation models are used operationally in many parts of the world for monitoring the effect of weather conditions on crop growth and for predicting crop yields from regional to continental scales (Challinor et al., 2004; Hansen et al., 2004; Nemecek et al., 1996; Thornton et al., 1997; Vossen and Rijks, 1995; Yun, 2003). The success of the crop yield forecasting system strongly depends on the crop simulation model's ability to quantify the influence of weather, soil and management conditions on crop yield and on the systems ability to properly integrate model simulation results over a range of spatial scales (Hansen and Jones, 2000).

The spatial and temporal variability of weather conditions are an important source of uncertainty when applying crop simulation models over large areas. Nowadays, two important sources of weather variables are often applied: (1) weather variables observed at weather stations are interpolated to the locations where the crop model is applied. Although the density of weather stations in many areas is often quite high, many stations do not report in near real-time making them unsuitable for near real-time crop monitoring applications. Due to the limited density of weather stations a

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considerable uncertainty is often present in gridded weather products derived from weather stations (de Wit et al., 2005). (2) Weather variables can be provided by numerical weather prediction (NWP) models such as applied by the European Centre for Medium Range Weather Forecasts (ECMWF). NWP models long time suffered from poor spatial resolution as the grid size of the model often was in the order of a 0.5–2°. Recent advances in computing have caused a steady decrease of the grid size of NWP models which now approaches 25×25 km.[2] A general problem with output from weather prediction models is still that modelled variables often do not compare well with ground-based weather variables and complex downscaling procedures are necessary to convert NWP weather variables into realistic weather variables on the ground (Bates et al., 1998; Charles et al., 2004).

Meteorological satellites such as the NOAA-AVHRR series or the MeteoSat series are capable of providing meteorological variables. In particular, MeteoSat provides good opportunities with its 30 min revisit interval and relatively (compared to NWP models) high-spatial resolution. MeteoSat imagery can be used for deriving estimates of global and net radiation derived from cloud cover and albedo, daily minimum and maximum temperature derived from day and night surface temperature and turbulent fluxes (latent and sensible heat flux) by applying a surface energy balance model (Rosema, 1993). Moreover, opportunities for rainfall estimates exist by integrating MeteoSat cloud cover estimates with rain gauge products.

Applications of MeteoSat-derived weather variables in mechanistic crop simulation models have so far been limited, but examples have been presented by Roebeling et al. (2004). The main reason is probably that, besides the processing effort needed to derive the meteorological variables from MeteoSat imagery, intrinsic differences exist between some of the variables measured on the ground and the variables derived from MeteoSat. For example, surface temperature derived from a satellite radiometer at noon often differs considerably from daily maximum air temperature measured at 2 m on the ground (de Wit et al., 2004). This makes ingestion of these variables in crop simulation models difficult because many biophysical relationships within these models (assimilation, respiration, etc.) have been calibrated on air temperature rather than radiometric surface temperature.

[2] http://www.ecmwf.int/products/changes/high_resolution_2005.html#resolution_changes.

This paper describes the results obtained by running a mechanistic crop simulation model on a combination of weather variables derived from MeteoSat imagery and weather variables interpolated from weather stations. MeteoSat-derived variables replaced station derived variables whenever possible. The overall objective was to determine if MeteoSat-derived meteorologic variables can be used as routine inputs to an operational crop monitoring system. More specifically, the objective of this study was to investigate the effect of MeteoSat-derived weather variables on the crop simulation results and on the relationship between simulation results and crop statistics at regional and national level.

2. Methodology

2.1. The crop simulation model

To assess the merit of using MeteoSat-derived meteorological products for crop modelling and yield forecasting, we used the World Food Studies (WOFOST) crop simulation model (van Diepen et al., 1989). WOFOST is a mechanistic crop growth model that describes plant growth by using light interception and CO_2 assimilation as growth driving processes and by using crop phenologic development as growth controlling process. The model can be applied in two different ways: (1) a potential mode, where crop growth is purely driven by temperature and solar radiation and no growth limiting factors are taken into account; (2) a water-limited mode, where crop growth is limited by the availability of water. Currently, no other yield-limiting factors (nutrients, pests, weeds and farm management) are taken into account.

The reduction in growth due to drought is quantified on a daily basis. As long as the soil moisture content is within the optimum range between field capacity and critical soil moisture content, it is considered sufficiently wet and there is no reduction in daily growth rate. But as soon as the soil dries out below the critical point, the water consumption by the crop (the evapotranspiration) is reduced with a factor from 1 to 0 in proportion with the soil moisture depletion between the critical point and wilting point. For a given soil, the wilting point is a fixed percentage soil moisture, the critical point is situated somewhere between wilting point and field capacity. For a given crop its exact position depends on the evaporative demand from the atmosphere, expressed as the potential evapotranspiration (ETp) for a closed green leaf canopy in mm per day. For low ETp values the critical moisture content shifts