

APPLICATION OF NON-HYDROSTATIC NUMERICAL MODELS DATA AND METEOROLOGICAL SATELLITES IMAGES TO INVESTIGATION OF AIRCRAFT FLIGHT CONDITIONS WITHIN CLOUDS SYSTEMS

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ABSTRACT:

The paper presents research results concerning developing software for determining optimum aircraft flight routes in severe weather. The application uses COAMPS mesoscale model data and MSG satellite images. The analyses concentrate mainly on forecasted fields of clouds and hazardous for aviation atmospheric phenomena - turbulence and icing. Gradient characteristics of the atmospheric state including frontogenetic function, temperature coefficient of fronts location and vorticity are used for investigating creation, development and dissipation of frontal zones, cloud systems and precipitation. The charts of physical properties in their gradient form enhance the standard analysis. The software is designed for operational use and for theoretical research of atmospheric phenomena' dynamics. It enables to look for and investigate quantitative relations between cloud systems observed on satellite images and in the meteorological elements fields. Numerous options of processing the mesoscale materials enable to use satellite images and charts of various combinations of meteorological fields within one session. Transformation of satellite images and COAMPS products to uniform cartographic projections facilitates simultaneous interpretation of various data, including non-standard ones, e.g. vertical profiles illustrating evolution of atmospheric conditions and various forms of spatial and temporal distributions of meteorological elements fields. This increases effectiveness of weather forecasting for optimizing flight time and route. The application includes programs for investigating the impact of mesoscale models parameterization on forecasts. These programs enable to compare numerically generated cloud fields with those observed in satellite images. The program will be developed by including orbiting satellites images, meteorological radar network data and new generation models data.

1. INTRODUCTION

Satellite images, being a representation of atmospheric emission of visible, infrared and microwave radiation, are used for investigating the state and dynamics of the atmosphere by means of analysis of cloud systems organization. Organized cloud structures are a good source of information concerning kinetic, potential and internal energy distribution as well as trajectories and vortices of air masses. Recognition and identification of the states of the atmosphere using satellite images is a part of photo-interpretation.

Satellite images combined with numerical weather prediction models' data and synoptic charts are mainly used for identifying location and development stage of pressure systems and atmospheric processes related with them, especially evolution of cyclones and atmospheric fronts, perfectly observable in animated series of satellite images.

A database of COAMPS (Coupled Ocean/Atmosphere Mesoscale Prediction System) mesoscale non-hydrostatic model of the atmosphere and research methods for comprehensive usage of satellite images were developed in the Faculty of Civil Engineering and Geodesy of the Military University of Technology, Warsaw, Poland for:

- ultra-short term forecasting of local processes in mesoscale,

- COAMPS model forecasting results verification using satellites images,
- detecting and recognizing phenomena invisible in synoptic charts,
- tracking unstable atmospheric processes and verification of their theoretical description.

Distribution of Earth surface and atmosphere's emission of radiation is the basic source of information about the atmospheric state and processes. Information concerning specific phenomena and states of atmospheric energy is distributed over various spectral bands of radiation recorded on board of the satellites and delivered to ground stations. For example, carbon dioxide emits in a different spectral band than water vapor, clouds emit in a few narrow bands while deriving information about temperature and humidity of air (mixture of gases) requires a few different spectral bands at the same time. Satellite measurement equipment records atmospheric radiation in numerous spectral channels, including:

- visible (VIS) – mainly radiation reflected from tops of cloud systems,
- infrared (IR) – tops of cloud systems and Earth surface's temperature,
- water vapor (WV) – distribution of humidity,
- microwave (MV) – e.g. for sea surface state assessment (waves).

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In addition to imagery channels, multispectral channels are recorded for determination of vertical profiles of temperature, humidity and ozone concentration.

2. METEOSAT SATELLITE IMAGES TRANSFORMATION TO CARTOGRAPHIC PROJECTION OF MESOSCALE FORECAST CHARTS

2.1 Meteosat satellite images format

The structure of a file containing a Meteosat satellite image is not compatible with the popular graphical formats. Each image is a matrix of points recorded in horizontal lines while each byte includes information concerning two adjacent points of images – pixels. The value appointed to each point is related with the level of radiation intensity recorded from elements of the observed object. For IR images it means that specific colours of the image are related with specific temperature ranges of the imaged elements. For VIS images it means that image elements are related with the level of the observed object illumination and its reflective properties. WV images are interpreted as information about water content in the observed area of the atmosphere. Thus, appointing colour scale to recorded values of radiation intensity enables to analyze the satellite images as distribution of a specific characteristics of the state of the atmosphere. The colour scale attributed to the values from the satellite image file is often user defined which provides capability to highlight elements of special importance to a specific analysis.

2.2 The ‘meteosat’ application

The ‘meteosat’ application (Fig. 1) developed by the paper authors automatically runs a series of operations related with an initial phase of satellite images transformation depending on the data source, e.g. images combining, cropping and supplementing with appropriate headers defining the bitmap parameters (color palette, size etc.) as well as defining the projection parameters.

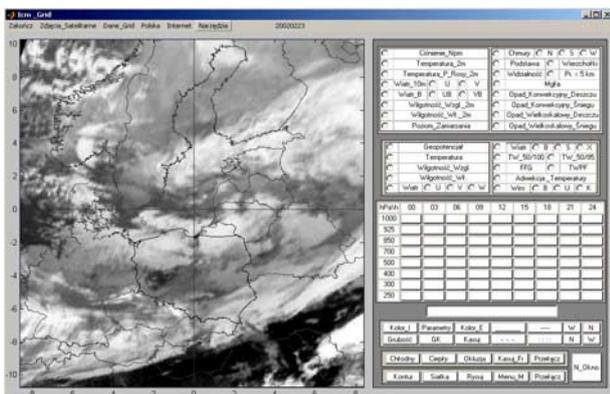


Figure 1. Dialog window of the ‘meteosat’ application.

The algorithm of satellite images transformation uses a large number of parameters related, first of all, with geometrical aspects of the process of scanning the atmosphere, e.g. these are the axes of the Earth ellipsoid, the distance from the ellipsoid’s center to the satellite or the scanning angle of the satellite radiometer. Most of the parameters are determined directly

from the images themselves. These parameters are used mainly for determination of the coordinates of the cartographic projection and for constructing the satellite image. Proper determination provides correspondence between the image and geographic grid of the represented area. Once the atmosphere scanning parameters are determined, the satellite image pixels are projected onto the surface of the rotational ellipsoid. This operation is equivalent to a second process (hypothetic) of scanning the atmosphere by the meteorological satellite’s radiometer. Its main goal is to reconstruct the shapes of the atmospheric areas from which the satellite collects information concerning the atmospheric radiation. The areas are convex quadrangles that form an irregular curvilinear grid on the ellipsoid’s surface. The geographic coordinates of the grids are defined by the intersection points of the ellipsoid and a straight line (the scanner axis). Such grid enables to transform the image into any cartographic projection.

In the final phase the ‘meteosat’ application uses pixel algorithms of shape approximation and grid cells filling with color corresponding with the original one on the satellite image. For fast transformation and appropriate precision for meteorological interpretation purposes, the current program version uses a simple algorithm of satellite image cells reconstruction. Application of complex algorithms is justified in cases of significant enlargements of the transformed images or for MSG images. Such enlargements may be useful in processes of assimilation of the mesoscale model input parameters.

Additionally, compensation of country borders contours, routinely added to the images, is applied during transformation. The contours may significantly influence the cloud cover analysis especially at the coasts. Due to specific properties of the natural projection of the satellite images (Earth observed from the satellite), areas in high latitudes, being at greater distances from the satellite, seem to contract. The areas spread during transformation to the mesoscale model projection.

3. COAMPS - COUPLED OCEAN/ATMOSPHERE MESOSCALE PREDICTION SYSTEM

COAMPS model was developed in the Naval Research Laboratory, USA. COAMPS uses modules that parameterize a number of phenomena: radiation transportation processes, cloudiness, precipitation, air flows in the turbulent boundary layer of the atmosphere, water vapor cycle, vegetation etc. The computational area of the model may be presented in a few cartographic projections. The vertical axis of the model is of the σ type which enables to mimic the orography. The model uses the embedded grid technology, i.e. models computed on grid of smaller spatial distance between the nodes obtain the boundary conditions values and parameters of state from grids of larger spatial distance between the nodes. A few different grids (areas of the forecast computation) are available at the same level of embedding.

COAMPS system uses boundary conditions and initialization fields (first approximation) from NOGAPS global model - Navy Operational Global Atmospheric Prediction System. Multiple Variables Optimum Interpolation (MVOI) 3-D technology is used for observations data control and analysis of the state of the atmosphere and oceans. NOGAPS model fields are available on GODAE server in the GRIB binary format. Forecast parameters of the COAMPS model include: the Exner function (ratio of the atmospheric pressure at a point in the

atmosphere to the atmospheric pressure at the surface below it), wind vector components (u , v , w), potential temperature, mixing ratios (water vapour, liquid water and ice crystals in clouds, rain, snow, drizzle), surface atmospheric pressure, land surface temperature and humidity, sea surface temperature, aerosols concentration etc.

The research conducted by the paper authors concerning COAMPS data processing concentrates on developing an operational mesoscale weather forecasting module for producing:

- charts presenting spatial and temporal structures of the fields of forecasted meteorological parameters at selected isobaric surfaces,
- cross-sections of the atmosphere for a selected region or along a route which present graphs and digital data concerning vertical distribution of forecasted meteorological parameters (e.g. wind speed and direction, wind vector components etc.),
- non-standard forecast charts in projections compatible with digital satellite images used for complex analysis of synoptic materials.

These will provide forecasting materials of accuracy currently unavailable for operational usage in meteorological stations. The module results may also be used as objective input data for operational forecasting methods of hazardous phenomena.

4. APPLICATION OF SATELLITE IMAGES AND MESOSCALE MODEL DATA TO WEATHER FORECASTING FOR AVIATION

Satellite data occur to be of special importance in complicated atmospheric situations when classical weather forecasting methods fail. It concerns mesoscale phenomena hazardous for aviation, e.g. intensive thunderstorms with pouring rain, hail, squalls and whirlwind. Due to high dynamics of changes in the phenomena, it is often not possible to produce an effective weather forecast for aviation using the routine synoptic materials. It is then necessary to make use of quasi real time data like meteorological satellite images and meteorological radars data.

Empirical procedures of weather forecasting are still applied in synoptical practice. They often yield good results only for limited areas fulfilling criteria for which they have been developed. Applying the methods to other areas requires considering microclimatic and environmental conditions of the specific region. Additionally, application of a specific forecasting procedure to a specific synoptic situation depends mainly on a subjective analysis made the meteorologist.

Comprehensive analysis of remote sensing data and forecasted data from mesoscale models enables to provide effective weather forecasts for aviation by applying objective analysis of the state of the atmosphere and its forecasted changes.

Fig. 2. presents a 24-hours weather forecast of the pressure field from the COAMPS model. The analysis of the chart indicates that weather over the territory of Poland is influenced by a trough of a low pressure system centred over Ukraine. The cloud base forecast is presented in Fig. 3. The forecast chart indicates that the cloud system complies with the trough. Forecast of precipitation sum (Fig. 4) complements the cloud base forecast. The forecasted values of precipitation sum range

from 1 to 3 mm with local maxima of 4 to 5 mm. All the information together indicate that there is an inactive occlusion front with cloud base of 600 to 2000 m over the territory of Poland.

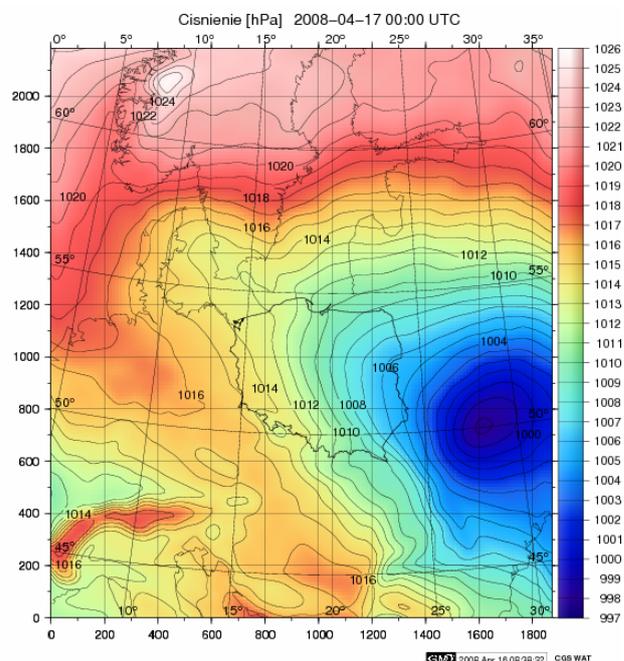


Figure 2. Weather forecast of pressure for 24-hours.

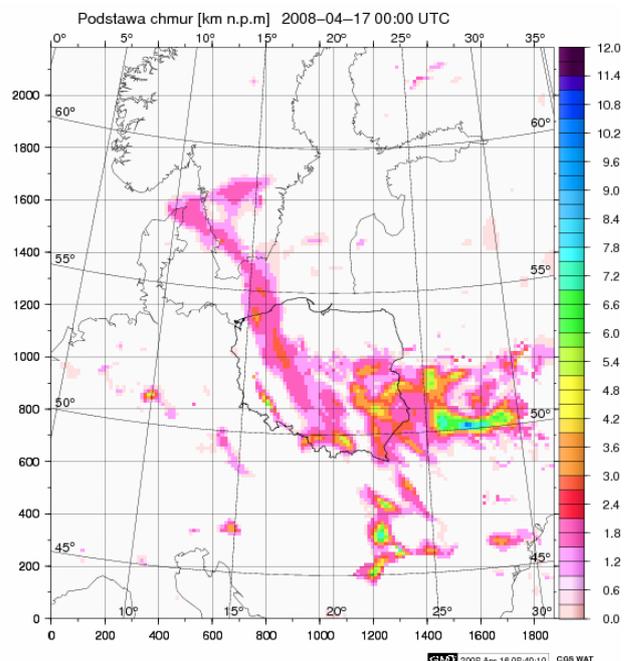


Figure 3. Weather forecast of cloud base for 24-hours.

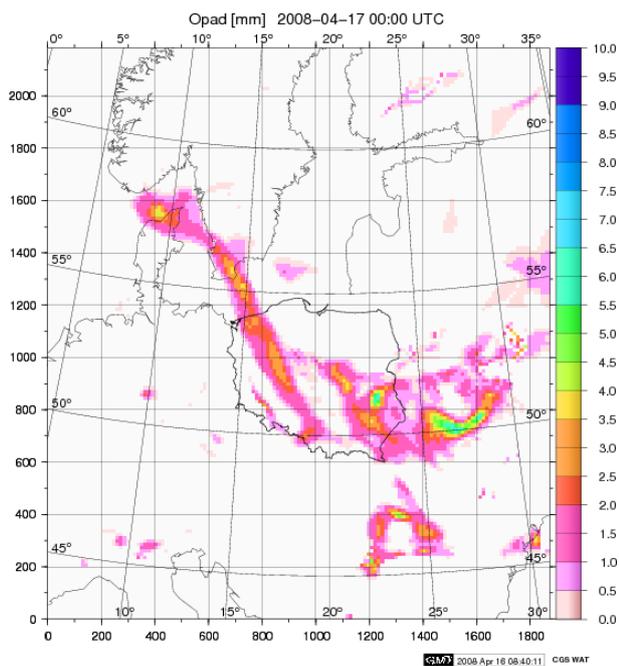


Figure 4. Weather forecast of precipitation sum for 24-hours.

Comparison of the 24-hours COAMPS forecast of cloudiness with the satellite IR image (Fig. 5) recorded at the time of the model forecasts indicates that the numerical weather forecast is effective.

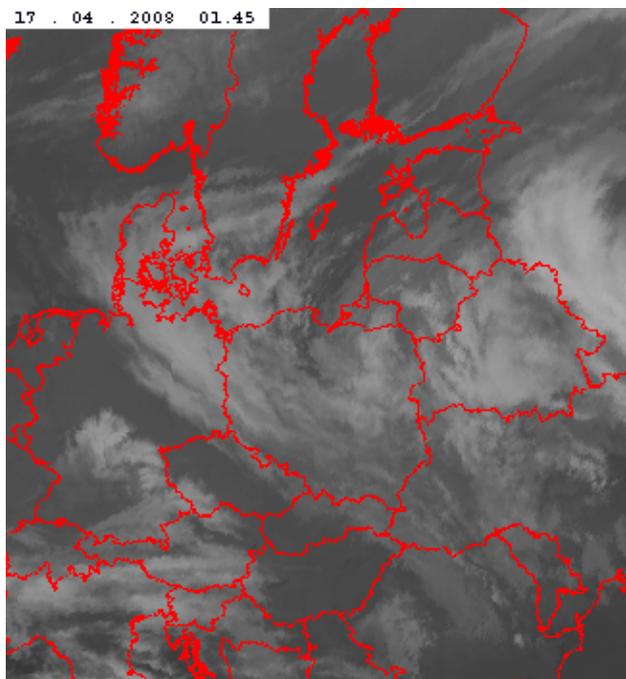


Figure 5. Satellite IR image (www.imgw.pl).

5. CONCLUSION

The authors assess that application of the proposed charts to synoptic practice might enable qualitatively new attitude to short term weather forecasting for limited areas. This would shift the basic importance to objective factors independent of subjective or routine data interpretation by the forecaster. The point of the proposed solution can be briefly described by the following:

- profounder usage of the knowledge of the atmospheric phenomena physics,
- efficient forecasting of the dynamics of atmospheric phenomena development,
- objective analysis of the space distribution of the meteorological parameters forecasted values and calculated characteristics of the atmospheric state,
- practical neglecting of the imperfect empirical methods of hazardous phenomena forecasting,
- charts preparation in projections corresponding to satellite images for complex analysis of the meteorological data.

The modular structure of the application enables to develop it by introducing new function modules to the main program. New features improving the performance and presentation are added systematically and extension of the input data range is planned. The application is currently used for research and operational exercises in the courses of dynamic, synoptic and satellite meteorology.

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