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DEVELOPMENT OF SATELLITE-BASED SIGNIFICANT CONVECTION NOWCASTING PRODUCTS IN SUPPORT OF AIR TRAFFIC MANAGEMENT IN HONG KONG

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1. INTRODUCTION

Nowcasting products are mostly based on extrapolation of radar echoes. The range of individual radar is limited and changes in local rainfall intensity may be abrupt. These factors, together with frequent updating of nowcasting products, may lure forecasters to focus on the local variation while overlooking changes in the weather condition over a larger temporal and spatial scale.

Since convective clouds over a large area shown on satellite images are relatively stable within a few hours and the extensive coverage of satellite imagery is in better match with the associated synoptic or mesoscale forcing, forecasters should find satellite imagery useful in assessing the development and movement of weather systems as a whole. This paper elucidates an attempt to apply auto-tracking algorithm, a common nowcasting technique, to satellite-based convection products with a view to forecasting the movement of significant convective clouds in the next few hours.

Verified with past significant convective cases, auto-tracking based on satellite imagery was found to be useful in forecasting the position of convective clouds for several hours into the future. The following sections introduce the prediction system, its verification results, and discuss the limitations and prospects of the system.

2. SATELLITE CONVECTIVE CLOUD PREDICTION SYSTEM

2.1 Basic principles and application

Forecasters experienced that convective cloud clusters of synoptic and meso-α (200-2000 km in accordance with Orlanski [1]) as seen on satellite images take no less than several hours to develop, mature and dissipate, whereas single-cell thunderstorms in the cloud clusters may form and vanish in tens of minutes. It is noted that cloud top temperature, which spans relatively longer in time, serves to indicate, to a certain extent, the life-cycle from formation to dissipation of the entire cloud cluster, and the motion of the cloud cluster also hints the large-scale movement of the entire system. Compared to the smaller scale convections as resolved in radar, the motion as seen from satellite is more stable and orderly.

Very short-range forecast for convective weather is very useful for air traffic control. Forecasts of convective activities for the flight information region in the following 0-6 hours can facilitate air traffic flow management.

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Originally, nowcasting refers to the approach of detailed description (primarily with remote sensing data) and extrapolation of weather up to 2 hours into the future [2]. Nowadays, nowcasting also covers extrapolation up to 6 hours [3]. The principles are to recognize the current weather system or phenomenon, estimate its motion (direction and speed) on the assumption that its intensity would not change significantly, and make prediction based on extrapolation. The Hong Kong Observatory has developed SWIRLS, a nowcasting system based on radar [4].

Single-cell thunderstorms resolved by radar are generally in the micro-α (200 m-2 km) to meso-γ (2 km-20 km) scale, with a life cycle of an hour or so [1]. As such, the assumption of constant system intensity is subject to inherent constraint. No matter how accurate the tracking and extrapolation scheme would be, forecast accuracy would unavoidably suffer from a sharp drop for a forecast range longer than one hour [5]. Considering that satellite imagery could depict the weather evolutions in a larger scale with life cycles up to several hours, one could apply nowcasting methods to satellite data in the hope of extending the effective forecasting range. Figure 1 shows a trial product on significant convection case of 22 April 2010. One can see that, the 6-hour extrapolation result still matched well to cloud clusters 6-hour later even though the weakening of the convection and the development over the southwestern edge were not accurately predicted. In light of the promising result in this case and a couple of others, the Satellite Convective Cloud Prediction System has been developed for trial.

(a) (b) (c)

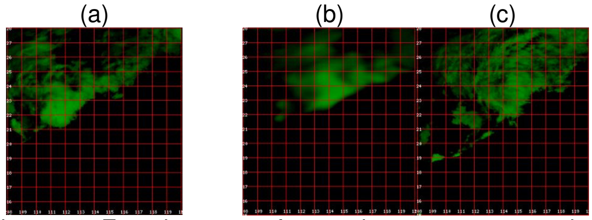

Figure. 1 Experiment on forecasting strong convective weather on 22 April 2010 (a) Satellite-based analysis product on convection for 02UTC that day; (b) 6-hour forecast by extrapolation; (c) Satellite-based analysis product on convection 6 hours later.

The Satellite Convective Cloud Prediction System consists of three modules. Individual module of the system is described in detail below.

2.2 Recognition of deep convection areas

The algorithm as in the deep convection monitoring tool is used for identifying deep convection areas [6]. Basically, temperature difference between the IR1 (10.3–11.3 μm) and the IR3 (IR3: 6.5–7.0 μm) channels of the MTSAT satellite is used to estimate the vertical extent between cloud top and tropopause. When IR1 temperature is closed to that of IR3, it reflects that the cloud top has reached the upper part of the troposphere or beyond which in turn serves as an indication of deep convection (red portion in Figure. 2(a)). The system uses this deep convection product as input to the tracking module.

(a) (b) (c)

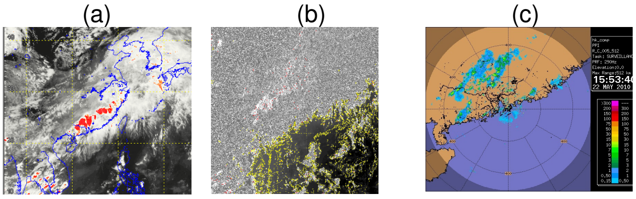

Figure 2: 08UTC, 22 May 2010
(a) Satellite-based product on deep convection;
(b) Satellite image of visible light;
(c) Radar image of reflectivity at 512-km range

2.3 Estimation of convective cloud motion vectors by optical flow method

Products on Atmospheric Motion Vectors (AMV) have been available for a long time ([7],[8]). However, their use is mainly for weather analysis and assimilation into numerical models. With sparse data, AMV can hardly provide sufficient data for extrapolating individual cloud clusters. As such, echo tracking tool similar to that employed in radar-based nowcasting was adopted for computing the entire 2-D motion field. In consideration of the large data volume of satellite data (1216 x 1352 pixels cf. 480 x 480 pixels from radar), the Satellite Convective Cloud Prediction System uses a computer program called VarFlow [10]. It is based on OpenCV [9]. The program implements a full multi-grid algorithm to solve optical flow between two consecutive images [11]. The program itself has been highly optimized so that computation generally completes within several seconds when applied to satellite images.

The VarFlow program requires two 8-bit grey-scale images as inputs. Satellite data is first converted into grey-scale images. The pre-processing program extracts data corresponding to the temperature difference of IR1-IR3 that ranges between 15K and -15K, and assigns, linearly, to the corresponding image pixel a value over 256 grey scales available. From experience, temperature differences exceeding 25K normally corresponds to the earth surface and need to be filtered. The floor of temperature difference of -15K was obtained from statistics.

The system feeds two grey-scale satellite images, separated with a one-hour interval, into the VarFlow program to compute the motion vector of each pixel. The control parameters of VarFlow are configured such that horizontal scale as large as 600 km and as small as 30 km, which are comparable with the scale of a tropical cyclone and thunderstorms, were chosen after several trials.

2.4 Extrapolation of cloud clusters with semi-lagrangian advection scheme

After obtaining the motion vectors of cloud clusters that completely fill the 2-D image, a simple semi-Lagrangian advection scheme is employed. Since two satellite images are separated with a one-hour interval, and in view of the diffusive property of the scheme, the time-step of extrapolation was set to one-hour. During initial trial of the system, time-steps of 30-minute and 10-minute were also tested but the results were all similar. It is possibly to be due to the stability of the semi-Lagrangian scheme with respect to time integration.

3. FORECAST PRODUCTS ON CONVECTIVE CLOUDS AND VERIFICATION

The Satellite Convective Cloud Prediction System was put in trial operation in August 2010. The system extrapolates hourly cloud positions up to 6 hours into the future, and provides an update every hour. In the general forecasting products, regions with IR1-IR3 less than 1K (red) and less than 3K (blue) were highlighted (Figure.3). In the aviation specific forecasting products for the Hong Kong Flight Information Region (Figure 4), areas of temperature difference less than 8K (yellow) and less than 1K (red) were highlighted.

(a) (b)

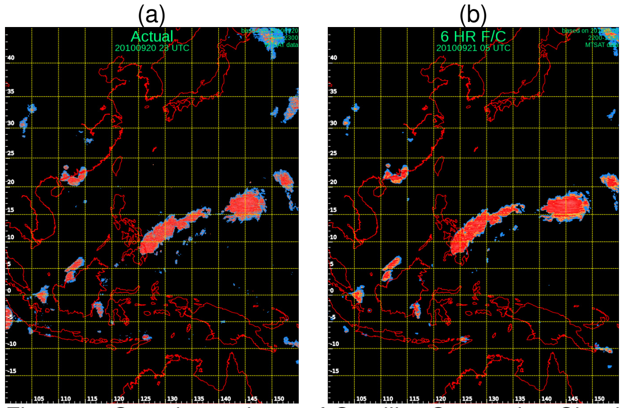

Figure 3: Sample products of Satellite Convective Cloud Prediction System. (a) analysis product on convection; (b) 6-hour forecast generated through animation of images of hourly forecast for forecaster's reference.

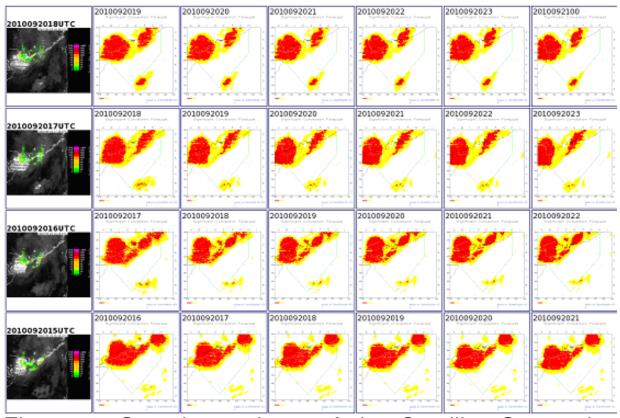

Figure 4: Sample products of the Satellite Convective Cloud Prediction System for the Hong Kong Flight Information Region. The left column shows satellite-based analysis products on convection superimposed on real-time radar images. Forecasts are updated hourly with the latest output put onto the top row.

The verification result for September 2010 is tabulated in Table 1. To eliminate boundary effect, the verification domain is the area bounded by 15°S-40°N, 105°E-150°E.

The verification result was expressed by contingency table categorized with respect to temperature difference of less than 3K. One can see from Table 1 that the CSI decreased with the forecast range. CSI decreased from 0.5 for 1-hour forecasts down to 0.14 for 6-hour forecasts. The verification is rather stringent in the sense that a forecast is regarded to be accurate only when the intensity and position of all pixels on the satellite image are accurately predicted. Table 1 showed that the system is, to a certain extent, skillful in forecasting up to 2-3 hours into the future as the POD and FAR both remain around 0.5.

Forecast Range	Portion of Detection (POD)	False Alarm Ratio (FARatio)	Critical Success Index (CSI)
1 hour	0.67	0.33	0.50
2 hours	0.53	0.47	0.36
3 hours	0.42	0.57	0.27
4 hours	0.34	0.65	0.21
5 hours	0.29	0.71	0.17
6 hours	0.24	0.75	0.14

Table 1: Verification result of the Satellite Convective Cloud Prediction System for September 2010

4. DISCUSSIONS

The Satellite Convective Cloud Prediction System is subject to inherent limitations. There are three challenges in extrapolating satellite images of clouds. Firstly, as the tracking scheme demands time-continuity, products from geostationary satellites have to be used. This in turn limits the number of remote-sensing channels available so accurate detection of cloud types, structures and moisture contents are not possible. Secondly, the tracked motion vectors are performed for cloud tops and only represent motion near cloud tops that may not be associated with the movement of convective core at the mid levels. Finally, as different cloud layers interlace and cover one another, the 3-D movement of cloud layers cannot be re-constructed with the extrapolation of motion vectors for a single layer. These problems pose difficulties to the forecasting system in all aspect of recognition, tracking and extrapolation of convective weather systems.

Due to the tremendous amount of data, it takes time to verify retrospectively all forecasting products for the whole rainy season in 2010. Nevertheless, subjective verification revealed the followings:

(i) At high latitudes, geostationary satellite suffers from parallax. In this regard, coupled with baroclinicity, false alarm of the current deep convection product in the high-latitude regime is subject to improvement;

(ii) Convection initiation and dissipation have not been taken into account. The system performed better for large cloud clusters with strong convection and marked movement;

(iii) For a number of cases, despite the verification scores were not high, the motion vectors obtained did serve as good references for forecasters;

(iv) The VarFlow control parameter used by the system were not capable of producing cyclonic wind field, thus the system could only capture the translation movement in tropical cyclone situation.

5. CONCLUSION AND FUTURE DEVELOPMENT

The Observatory developed the Satellite Convective Cloud Prediction System by applying nowcasting techniques to satellite data. The system is, to a certain extent, skillful as it achieved a CSI of 0.27 in the forecast range of 2-3 hours. To get better insight into the system's characters, we seek to verify it with more cases; and re-design the verification scheme with a view to assessing the performance of the system based on operability and practicality.

In concert with of the copious new developments in satellite application in recent years ([12], [13]), we set sights on capturing thunderstorms development based on satellite data and finding a cure for the existing shortfalls of the satellite-based forecasting products by making use of newer techniques

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