Derivation of Motion Vectors from Sequential Satellite Images using Vague Contouring

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Abstract – A relaxation-contour method for retrieving motion vectors from sequential satellite images is presented. The contour part explores image contours (level set) to extract targets (extreme points on these contours). Motion vectors are derived by examining the correspondence between targets extracted from symmetrical pairs of images. The basic criterion is geometrical similarity of contours taken at the same level (contour matching), while gradient information is used to sustain robustness of search. Vague contouring generates much more motion vectors than by the current template matching methodology. Naturally, many invalid vectors are generated in this way, yet their abundance gives preferentiality to a relaxation labeling approach aimed at selection of correct vectors from several candidates to be consistent (in space and time) with others. Estimates of water vapor motion vectors obtained using relaxation-contour and maximum cross-correlation (with and without relaxation labeling) methods have been compared to those derived manually. Results show advantages of the relaxation-contour method both in density and quality. We contemplate future integration of this scheme with assimilation models.

Keywords: motion vectors, contour and template matching, relaxation labeling, level set methods

1. INTRODUCTION

Derivation of motion vectors (MV) from sequential satellite images is a traditional problem in remote sensing of atmosphere and ocean dynamics. First, in satellite meteorology, cloud motion vectors (CMV) became available from geostationary satellites, and cloud motion winds together with water vapor motion vectors (WVMV) are derived operationally nowadays. An excellent historical summary of this development may be found in Menzel (2001). The problem of tracking motion on sequential satellite imagery is indeed more general. It also includes retrievals of sea surface currents (SSC) from infrared (IR) or color images, wind and current driven sea ice motion vectors from synthetic aperture radar or visible images.

Our experience with the human-based manual feature tracking (MFT) technique imparts us two things: 1) for selecting traceable features, chaotic cloudy and amorphous water vapor images should be first structured by contouring; 2) an answer to question what are best tracers requires global (synoptic) information. Without human synoptic vision (at least on this step, because assimilation models possess an equivalent), any MV retrieval scheme has to solve an implicit "many-to-many" problem of choosing reliable vectors on a pair of sequential images.

This comprises two reliant subproblems: localization (via extraction) and identification (via matching) of tracers on both source and destination images. It is well known (in computer vision) that the contour matching better solves the first subproblem, while the template matching – the second. It is simply because of different requirements: precise localization implies as few as possible pixels involved, while valid identification – as lots of. Normally, a trade-off between localization accuracy and reliability of matching is achieved by combining strong sides of both approaches: border (i.e. contour) matching supports interior (i.e. template) matching and vice versa. It is yet impossible to make such a beneficial union when one of the halves is inchoate, as for the current MV retrieval schemes based solely on template matching. There are only few works on contour matching of cloud motion winds (e.g. Mukherjee and Acton, 2002) or of similar (by matching patterns) wind and current driven sea ice motion (e.g. Vesecky et al., 1988) – but none for WVMV and relevant derivation of SSC. On the other hand, large number of studies was carried on the maximum cross-correlation (MCC) method based on template matching (e.g. Ninnis et al., 1986; Wu et al., 1992; Nieman et al., 1997; Gao and Lythe, 1998; Holmlund, 2002).

Remaining at the core of current MV retrieval schemes, the conventional MCC method often performs poorly and the fields obtained thereby are often characterized by obviously non-realistic divergence or vorticity values. Numerous researchers pointed to such drawbacks as difficulties in cases of rotation and scaling, in resolving multi-modal situations, and to its high computational burden. However, a major shortcoming of unresolved tracers has not yet attracted proper attention. In both received MCC and new contour methods suitable targets are typically that have the highest contrast and largest amount of standard deviation. We demure at such obtained targets and we want therefore to amend the choice by template matching – because would such targets extraction from a source image was unfailing, why not to do the same from the destination image and then simply to examine correspondence between two sets of targets? Concurrent

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contour methods examine this correspondence but are also restricted to features with strong contrasts usually appearing as edges of field discontinuities. For example, (Mukherjee and Acton, 2002) "…focus on the tracking of cloud boundary features, instead of correlating unreliable internal intensity features". However, cloud margins as well as ice floe borders are the most deformable features in question.

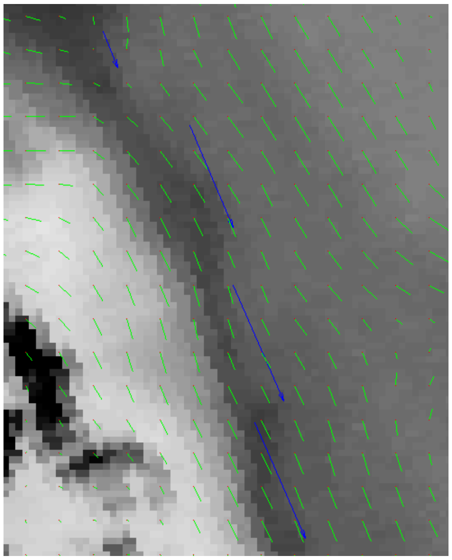

Figure 1. SSC vectors derived with the MFT technique (blue) and dominant contrasts orientation (green) for the First Oyashio Intrusion (Alexanin and Alexanina, 2001)

There is a serious problem facing such naïve idea of tracers selection, especially for SSC and WVMV retrievals: both template and edge-detecting contour matching schemes cannot correctly resolve the velocity component along the edge of a property depicted in the images because any small displacement parallel to the edge essentially maps the spatial pattern into itself. This well-known aperture problem is further aggravated in atmosphere and ocean remote sensing due to geostrophic balance causing strong gradients to occur just across image isotherms as a result of flow shearing. The overall problem is clear now: Those ambiguous tracers well resolved by rigid templates and edge-detection operators due to their high contrasts may conceal indistinct but unambiguous ones (Fig. 1). As a result, many proper MV derived with the MFT technique cannot be revealed by either the MCC method or the modern contour methods because strong edges mask neighboring (even more numerous) vague features making them unidentifiable. The ability of retrieval method to extract currently unresolved vague tracers becomes thus a key to cope with the aforementioned aperture problem.

Revising the problem of unresolved features, a new approach to detection of vague contours was proposed in (Bobkov et al., 2001). The relaxation-contour (RC) method using vague contouring of sequential satellite images and quality controlled reanalysis of tracers was developed next and applied to determination of sea surface current vectors from satellite images (Bobkov et al., 2003). The RC method is aimed at contouring internal intensity features whatever vague they are. Subsequently, neither region segmentation nor border clustering procedures is required. In this study, we apply the RC method to derivation of WVMV comparing it to the MCC method, with and without relaxation labeling.

2. DETERMINATION OF TRACERS BASED ON VAGUE CONTOUR ANALYSIS

In the vague contour analysis, tracers are obtained using level set image representation. According to the level set theory, every image can be converted to graphic (contours) and vice versa. Moreover, levels provide the only global information available on this step. The current implementation of the RC method generates contours in three steps: 1) set of pixels borders are found among pixels of unequal levels (up to 256 levels on a grey-scale bitmap image); 2) borders of the same value are concatenated into chains; 3) polyline simplification is performed based on the algorithm of Douglas and Peucker (1973) but filtering out all pixel vertices to obtain vertex simplified polylines. The tracers extracted from these vertex simplified polylines are those vertices passing very subtle angle and gradient threshold tests. Vector-candidates connect similar by combined properties (form, level, gradient) tracers on different images. The output of vague contour analysis is thus a correspondence set of potential MV. The basic criterion for this correspondence is geometrical similarity of contours taken at the same level, while gradient information is used only to sustain robustness.

Of course, along with correct vectors many invalid ones are generated in this way, yet their abundance gives preferentiality to a relaxation labeling approach constituting the second part of the relaxation-contour method. The RC method confronts the current feature extraction scheme and, implicitly involving all image levels, does not require any image enhancement.

3. WVMV DERIVATION VIA QUALITY CONTROL BY RELAXATION LABELLING – MIDWAY TO ASSIMILATION MODELS

The current MV searching strategy, with or without the use of forecast as searching guide, is based on local information that cannot guarantee faithfulness of results. For further reliability, Wu (1995) has expanded the MCC by combining target selection and multimodal MCC scheme with relaxation labeling (Correlation-Relaxation, CR) method. It is evident that Wu's approach is an attempt to improve results of the MCC method by some sort of combinatorial search strategy using neighboring (mid-global) information. On the other hand, concurrent contour methods avoid the combinatorial search problem either by contour matching (Vesecky et al., 1988) or by ordering constraint (Mukherjee and Acton, 2002) relying on local information only. To the contrary, the RC method intends to explore the full-size correspondence set relying on global information via relaxation selection (resembling nudging techniques of assimilation models), hence greatly diminishing the role of both template and contour matching. This is definitely differs from variety of local correlation maximums considered by Wu et al. undermining the very idea of correlation-relaxation by: 1) generating a set of feature points in positions associated with significant image intensity variations or with high gradients – this part is similar to that used in the recent MV retrieval schemes that does not ensure the selection of proper vectors; 2) choosing the label set of vector-candidates from correlation coefficients that are above a certain threshold in the cross-correlation matrix – it is dubious because such procedure does not guarantee selection of local maximums (e. g. because of shoulders, ridges etc). Nonetheless, in this study we apply Wu's approach at hand to the correspondence set of vaguely contoured tracers using mid-global information: The relaxation procedure iteratively selects correct vectors from several candidates to be consistent (in space and time) with others.

4. METHODS IMPLEMENTATION AND COMPARISON

Methods comparison was carried out on a sequence of four water vapor images (6.7 µm) from GMS-5 on September 1, 1997 with hour intervals (taken from GMSLPW movie-loop "Glimpse around Japan"). Cloudy pixels were masked, so results obtained refer to clear-air situations. WVMV derived using three automatic methods were compared to those derived by MFT technique. Estimates of water vapor motion vectors were obtained using the relaxation-contour and the maximum cross-correlation (with and without relaxation labeling) methods and have been compared to those derived manually. The MCC method was implemented on an equidistant grid (baseline 32*32 pixels) in close agreement with the former EUMETSAT scheme. We have tried to implement the CR method proposed by Wu et al. but could not find enough local maximums on the correlation coefficient matrix calculated from water vapor images to do this explicitly. For compatibility with the RC method, an inverse modification of the CR method (called Relaxation MCC, RMCC) was implemented by positional shifting of templates on the source image. The centers of these overlapped templates became tracers to be tracked by the MCC method, with matching positions on the search image to be selected through relaxation labeling.

Table 1. Quantitative Comparison of Retrieval Methods.

Methods	**MFT**	**MCC**	**RMCC**	**RC**
Number of Vectors	67	93	333	480
Comparisons Number	46	68	211	242
Average Speed (m/s)	18.7	17.0	16.8	21.6
Std Deviation (m/s)	2.8	11.4	6.3	4.4
RMS Difference (m/s)	4.9	17.9	10.8	9.5
Speed Bias (m/s)	0	–0.9	–1.2	2.1

The methods comparison was carried out using the generally accepted technique, inside a circle of 20 pixels radius corresponding to the maximal displacement of tracers. Quantitative results of the method comparisons are given in Table 1. Manually tracked WVMV were compared by themselves using the same technique. The MCC method was applied only to the central pair of images. For the RC and RMCC methods, WVMV were derived from all four images. The results show advantages of the relaxation-contour method both in density and quality.

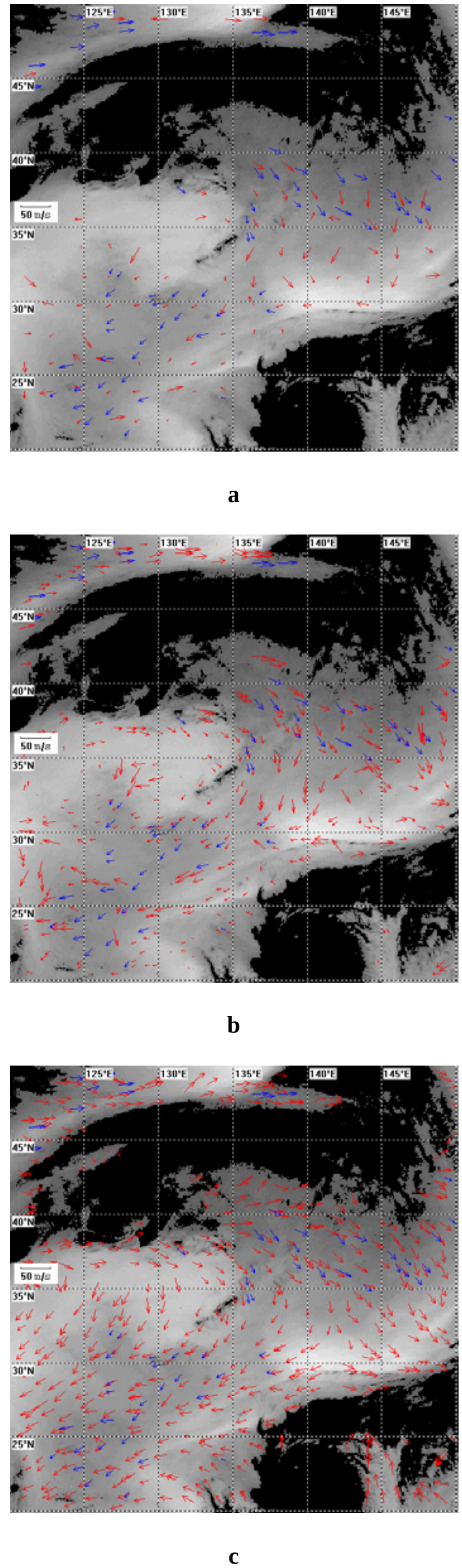

Figure 2. Qualitative Comparison of WVMV Retrieved by Automatic Methods (red) to MFT vectors (blue): a) MCC; b) RMCC; c) RC

In particular, there is no low speed bias found. Surely, the RMS difference between the RC and the RMCC methods was not so great but the results are much better than for the standard MCC method. It is necessary to notice that WVMV derived using the MCC method have not been quality-controlled, while relaxation labeling accomplishes such functions. At least, the RC method is the only having the positive speed bias (the overestimation of speed as compared to MFT vectors) while the underestimation of speed (low speed bias) is usually observed. The most convincing is yet the results of qualitative comparisons demonstrated in Fig. 2. It is obvious that only the RC method provides a detailed structure of the wind field, and WVMV have been derived even in those places where the manual technique was unsuccessful, and this may explain the speed overestimation observed.

5. CONCLUSIONS AND FUTURE WORK

We comment on the need to revisit current MV retrieval schemes based solely on the template matching approach, and contemplate two routes for future development: 1) better contouring of imagery and 2) feedback assimilation of MV in numerical models. First, contouring was recognized to be a formidable problem that is responsible for failure of our initial attempts to apply the RC method to derivation of cloud motion vectors. The present crude contouring algorithm allows intersecting contours and it is unable to delineate tiny filamentary features. It is supposed to amend the situation by utilizing newest multiscale geometric representations like curvelets, contourlets, bandelets. Second, regardless of the contouring algorithm roughness, the RC method was able to extract useful features unresolved neither by template matching (the MCC method), nor manually. This was because the strategy was changed toward drawing out as many as possible potential tracers, remaining thus more space for further quality control. However, a valid recognition of best tracers cannot be made locally. Further efforts are required for incorporating human synoptic vision into MV retrieval schemes, and this can only be made via specialized assimilation models with sequential relaxation. We came thus to direct involvement of numerical models in MV retrieval both for better contouring and for selection of useful tracers – a feedback assimilation process. For our research efforts focusing on filamentary phenomena such as upper tropospheric jet-streaks, atmospheric rivers and oceanic streamers, MV with highest possible density are required, and we consider a specialized assimilation model emphasizing advection terms, e.g., based on the CASL model (Dritschel and Ambaum, 1997).

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