Multi-Satellite Cloud Product Generation Using Canonical Coordinate Features

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Abstract

Cloud products derived from the MODerate resolution Imaging Spectroradiometer (MODIS) instrument, are generally accepted as state-of-the-art by the meteorological community. These products are, now, more widely used by the scientific community than those derived from traditional cloud products. These products, however, are only available twice/day over a specific geographic region. Algorithms that create MODIS products cannot be simply applied to other satellite data. Thus, an innovative method is needed to create MODIS-like products using a geostationary operational satellite, which has a higher temporal frequency and a wider coverage area. This project presents a Canonical Coordinate Decomposition (CCD)-based method to generate MODIS-like cloud products using imagery from the geostationary Satellite, namely Meteosat 8.

Acknowledgements

This research is supported by the Department of Defense (DoD) Center for Geosciences / Atmospheric Research at Colorado State University via Cooperative Agreement # DAAD19-02-2-0005 with the Army Research Laboratory.

Motivations

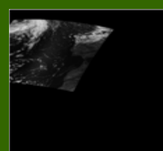
1. Current automatic cloud classification methods rely on *subjective* and *global* human expert labeling of cloud types. While this labeling captures some information about altitude of clouds, it cannot provide any useful information about their physical composition (e.g. ice, water or mixed).
2. Polar orbiting MODerate resolution Imaging Spectroradiometer (MODIS) satellite is used to provide scientific state-of-the-art cloud products. However, its temporal frequency and coverage area is significantly limited.

Main Goals

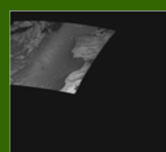
- **Use operational geostationary Meteosat 8 satellite to create scientific quality MODIS-like cloud products at higher temporal frequency and for larger area.**
- **Find features in Meteosat 8 multi-spectral channels that are most coherent with those of MODIS channels.**
- **Develop a method for temporal updating of the coherent features for new Meteosat 8 and at times when MODIS data is not available.**

MODIS and Meteosat 8 Imagery

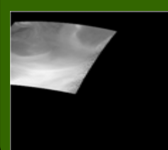
- **MODIS**
  - Aboard two polar orbiting satellites – *Terra and Aqua*
  - 36 distinct spectral channels at spatial resolutions of 0.25 km, 0.5 km, and 1 km.
  - Complete global coverage every one to two days.
  - 19 of 36 channels are used in *cloud mask* product.
    - 10 visible
    - 7 infrared
    - 2 water vapor
  - Cloud mask algorithm employs series of visible and infrared thresholds and consistency tests to specify confidence for cloud and no-cloud regions.
  - *Cloud phase* product created using cloud mask and 2infrared channels provides cloud compositions I.e. ice, water and mixed phase.
  - These products are considered to be state-of-the-art in meteorology.



Visible – 0.645 µm



Infrared – 3.71 µm

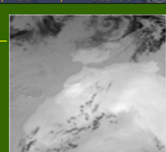


Water Vapor – 6.75 µm

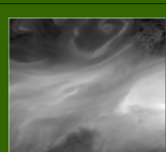
- **Meteosat 8**
  - Primary mission: continuous observation of earth's full disk
  - Geostationary over 0° longitude
  - Data returned every 15minutes
  - 11 distinct spectral bands with sampling distances of 3 km at nadir
  - Substantially greater spatial coverage than MODIS

Meteosat 8 Year 2004, July 8th day, hour 12, minute 00

Visible – 0.635 µm



Infrared – 3.9 µm



Water Vapor– 6.25 µm

Covers South Atlantic Ocean Mauritania, Africa (SW) to parts of Europe Italy and Germany (NE).

Data Preparation

- Channels from MODIS used in cloud mask generation process and all channels of Meteosat 8 are combined to create a two-channel system.
- Each pixel of MODIS and Meteosat 8 at different spectral bands form vector realizations of the corresponding random vectors.
- Visible, infrared, and water vapor channels are combined into three separate wavelength sample vectors
- Samples of MODIS and Meteosat 8 are separated based on their location over *land* versus over *water*.
- A total of six sets of data are thus created: visible over land, visible over water, infrared over land, infrared over water, water vapor over land, and water vapor over water.

Canonical Coordinate Decomposition

- An ideal tool to study linear dependence or coherence between two-channel data
- Applications in signal detection, classification, filtering and data compression
- In this case, two-channel data correspond to MODIS ($\underline{x}$) and Meteosat 8 ($\underline{y}$)
- Channels are zero mean and share the composite covariance matrix

$$\begin{bmatrix} R_{xx} & R_{xy} \\ R_{yx} & R_{yy} \end{bmatrix} = E\left[\begin{pmatrix} \underline{x} \\ \underline{y} \end{pmatrix} \begin{pmatrix} \underline{x}^T & \underline{y}^T \end{pmatrix}\right]$$

- Singular value decomposition (SVD) of the coherence matrix, *C*, is

$$C = R_{xx}^{-1/2} R_{xy} R_{yy}^{-T/2} = FKG^T \qquad F^T C G = K$$

$$F^T F = I, \quad G^T G = I, \quad K = diag[k_1, k_2, \ldots, k_n]$$

- The canonical coordinates of the original vectors are

$$\begin{bmatrix} \underline{u} \\ \underline{v} \end{bmatrix} = \begin{bmatrix} F^T & 0 \\ 0 & G^T \end{bmatrix} \begin{bmatrix} R_{xx}^{-1/2} & 0 \\ 0 & R_{yy}^{-1/2} \end{bmatrix} \begin{bmatrix} \underline{x} \\ \underline{y} \end{bmatrix}$$

- The correlation matrix K represents the contribution of each canonical correlation to the mutual information J between the original vectors, i.e.

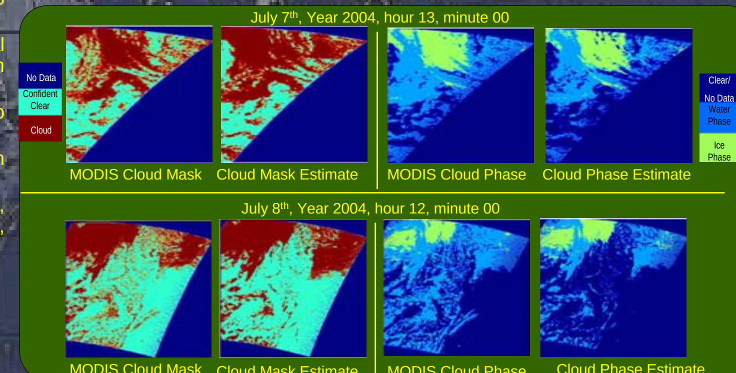
$$J = -\frac{1}{2} \log \det\{I - KK^T\} = -\frac{1}{2} \sum_{i=1}^{n} \log(1 - k_i^2)$$

- The canonical coordinate features that retain 70% of the mutual information are utilized for classification purposes.
  - 2 visible canonical coordinates (out of 3)
  - 3 infrared canonical coordinates (out of 6)
  - 1 water vapor canonical coordinate (out of 2)

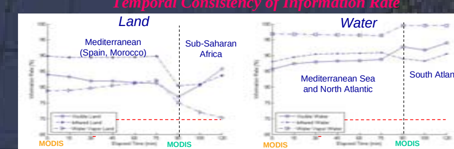
Neural Network Mapping

- A set of eight back-propagation networks is used , each specialized on the data within a two hour period over either land or water. This allows for covering the entire duration of daytime hours.
- BPNN's were trained based on the 6-D feature vectors of Meteosat-8 using MODIS overpasses in the week of July 7th, 2004 through July 15th, 2004.
- Outputs correspond to classes for MODIS-like cloud mask or phase generation.

MODIS-Like Cloud Product Results



Temporal Consistency of Information Rate



July 8th, 2004 (start 12:00 UTC, end 14:00 UTC)

- The block power method is applied for temporal updating of canonical coordinate features of Meteosat-8 at times and locations where MODIS is not available.
- Cloud mask estimates at concurrent overpasses of MODIS and Meteosat 8 have overall correct classification rates of approximately 85-91%.
  - Over land, majority of misclassifications are caused by certain land features.
  - Over water, clear pixels are correctly classified while some cloud pixels are misclassified.
  - Majority of uncertain and partly cloudy pixels are classified as clear.
- Cloud phase estimates at concurrent overpasses have overall correct classification of approximately 93-98%.
  - Cloud water phase is almost entirely correct, while ice phase seems to contain speckled errors. The errors happen mostly over land.
  - Other misclassifications occur in regions of mixed phase.

Conclusion

- **Preliminary results of the proposed CCD feature extraction show the great promise of this method with the data correlation and reduction between MODIS and Meteosat 8 channels.**
- **Data in canonical coordinates of Meteosat 8 reveals information concerning the different spectral relationships of the channels for MODIS and Meteosat 8.**
- **Cloud mask classification has been limited to definite classes of clear or cloudy regions. However, the results within these regions are very good.**
- **Cloud phase determination after forming the cloud mask has been highly effective for ice and water classes .**

Future Work

- **Improve the Cloud Phase mapping to include the mixed phase class.**
- **Investigate other neural network mapping methodologies.**
- **Extend the methods for overnight cloud mask/phase generation when visible channel is not available.**
- **Extend to other application areas including CloudSat project , aerosols and Ocean thermal monitoring.**