Distinguishing Cloud and Haze by Satellite Imagery Using Fuzzy Clustering Method

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About haze episode

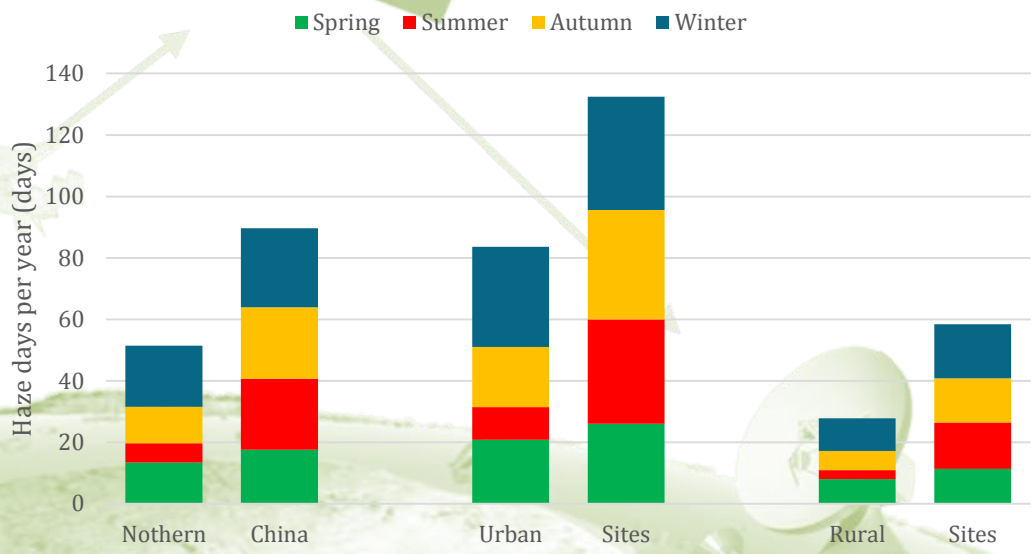
What is haze

- Haze is pollution phenomenon caused by suspend fine particles
- Deterioration of visibility, influencing transportation
- PM2.5 particles harming human health

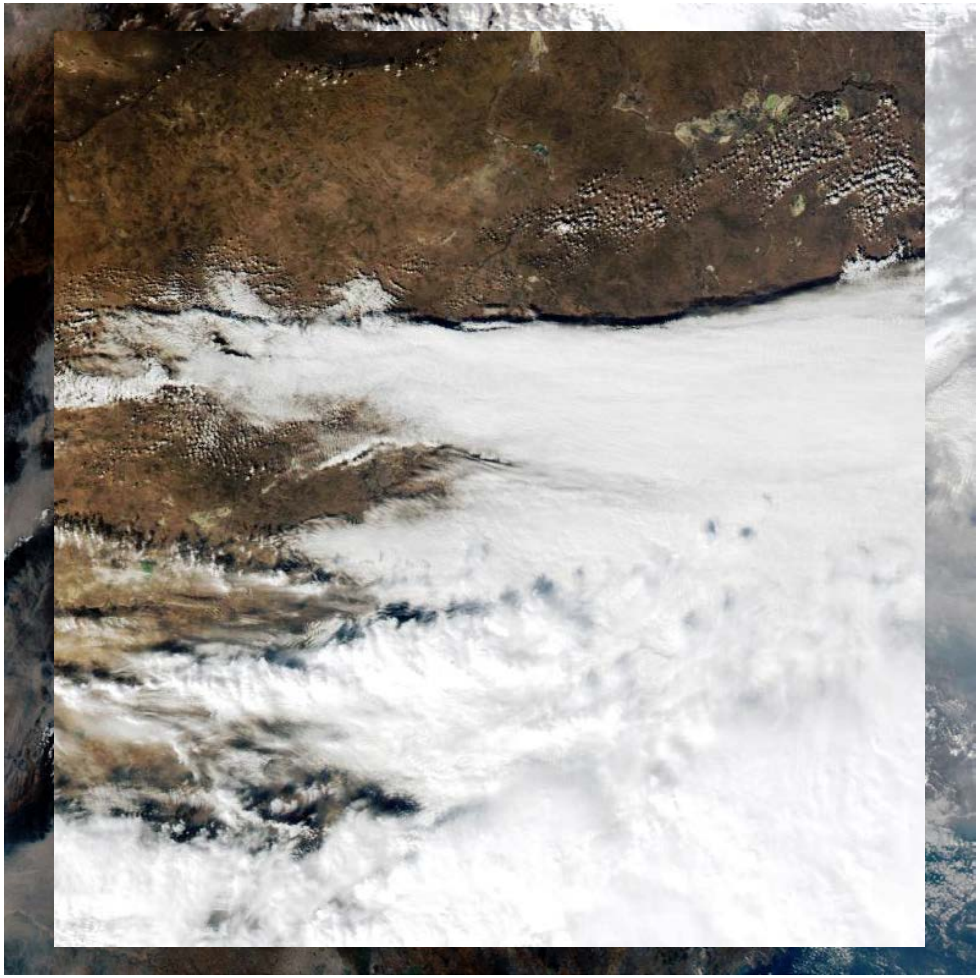
Haze in China

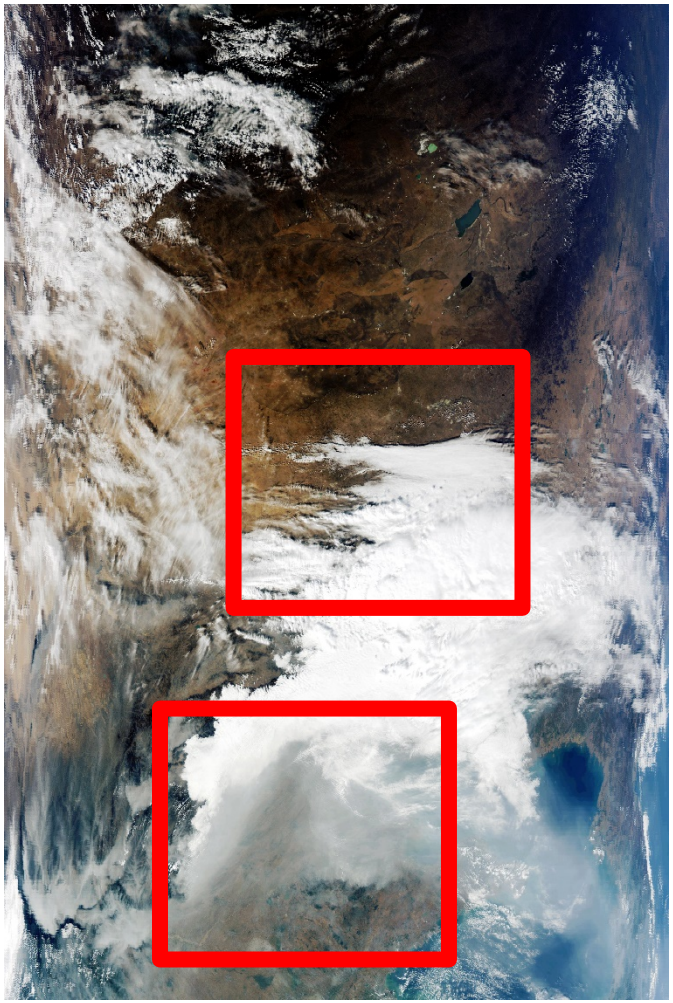
- Continued increasing in last 50 years
- Rapidly increasing in 21th century
- High attention paid by government environment division

Annual haze days in China during 1960s and 2000s



Haze and cloud in satellite imagery





MODIS AQUA RGB image, Oct 20, 2015. Northeast Asia

Conventional cloud detection algorithms

- Infrared brightness temperature thresholds and difference tests

$$BT_{11} < 270K$$
$$BT_{8.6} - BT_{11} > -3.7 - 1.6\ln(PW)$$
$$BT_{11} - BT_{12} < -0.51 + 0.49\ln(PW)$$

- Non-cloud obstruction flag and suspend dust flag

$$BT_{11} - BT_{12} > -1K$$
$$BT_{3.75} < 350K$$
$$R_{2.1} > 0.20$$

- Near infrared cirrus test

$$R_{1.38} > 0.035$$

- Spatial variability tests (new for MODIS collection-6 aerosol products)

$$\rho_{0.47} > 0.4$$
$$\sigma^{*}_{0.47} > 0.0025\ , \sigma_{0.47} > 0.0075$$
$$\rho_{1.38} > 0.025, \sigma_{1.38} > 0.003$$

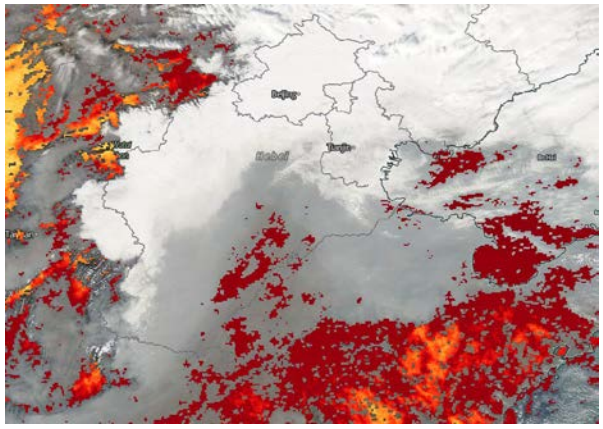
Band	Wavelength (nm)	Resolution (m)
1	620 – 670	250
2	841 – 876	250
3	459 – 479	500
4	545 – 565	500
5	1230 – 1250	500
6	1628 – 1652	500
7	2105 – 2155	500
8	405 – 420	1000
9	438 – 448	1000
10	483 – 493	1000
11	526 – 536	1000
12	546 – 556	1000
13	662 – 672	1000
14	673 – 683	1000
15	743 – 753	1000
16	862 – 877	1000
17	890 – 920	1000
18	931 – 941	1000
19	915 – 965	1000

Band	Wavelength (μm)	Resolution (m)
20	3.660 – 3.840	1000
21	3.929 – 3.989	1000
22	3.929 – 3.989	1000
23	4.020 – 4.080	1000
24	4.433 – 4.498	1000
25	4.482 – 4.549	1000
26	1.360 – 1.390	1000
27	6.535 – 6.895	1000
28	7.175 – 7.475	1000
29	8.400 – 8.700	1000
30	9.580 – 9.880	1000
31	10.780 – 11.280	1000
32	11.770 – 12.270	1000
33	13.185 – 13.485	1000
34	13.485 – 13.785	1000
35	13.785 – 14.085	1000
36	14.085 – 14.385	1000

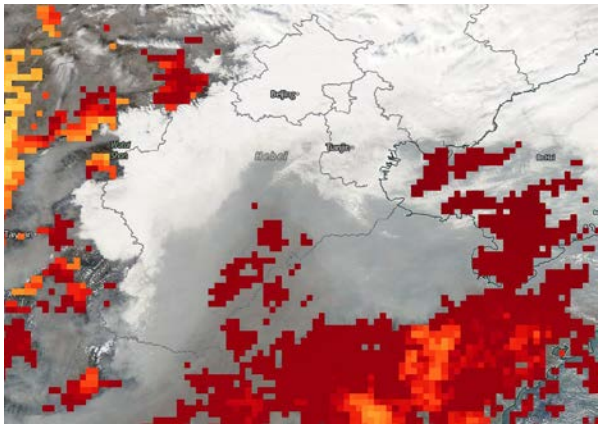
Space & possibilities of optimization

- Uses too many fixed threshold tests.
  - Thresholds need to be clear-cut and explicit, and need to be updated according to new observation findings.
  - Does not lead to uniquely good result in different scenarios.
- Hardly uses information other than pixel reflection.
  - Ignores many important characteristics that help distinguishing cloud and haze.

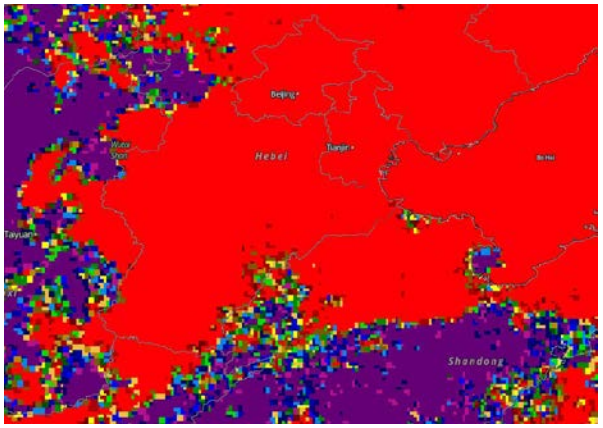
- This leads our goal being
  - Decreasing the number of fix threshold tests.
  - Decreasing the use of unnecessary bands, while considering more features of cloud and haze.
  - Confirming good results in different local cloud-haze interacting scenes.



MYD35, AOD, 3km



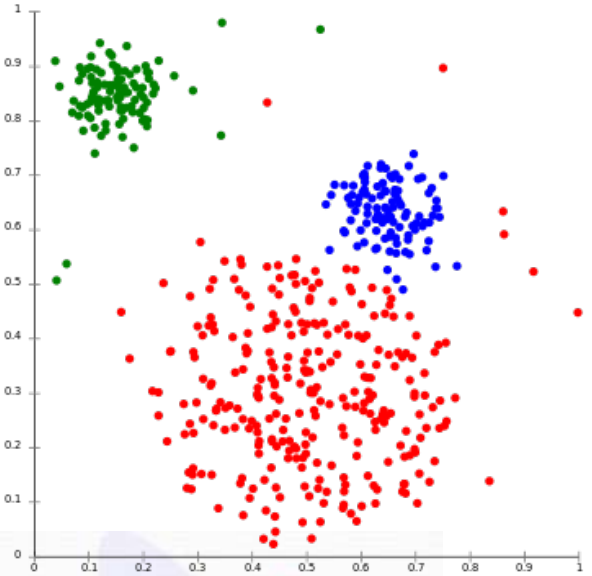
MYD35, AOD, 10km

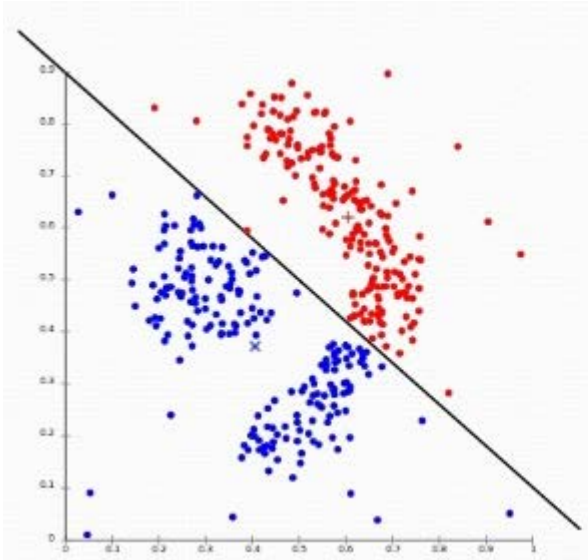


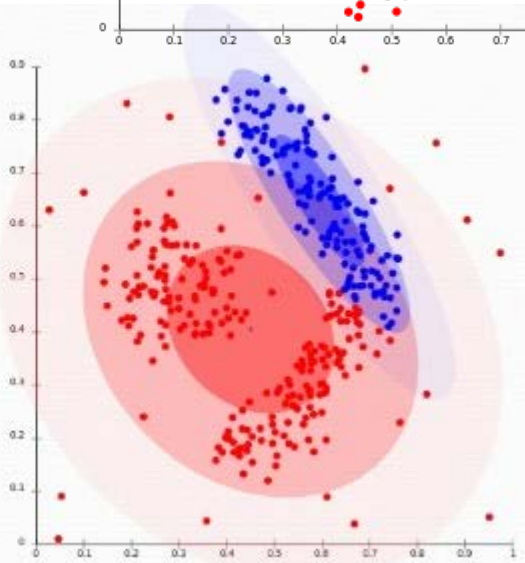
MYD06, cloud fraction, 5km

Fuzzy clustering method

- **Machine learning** gives computers the ability to learn without being *explicitly* programmed.
- **Clustering** involves assigning data points to clusters, or homogeneous classes.
- In **fuzzy** flustering, each data point can belong to more than one cluster.





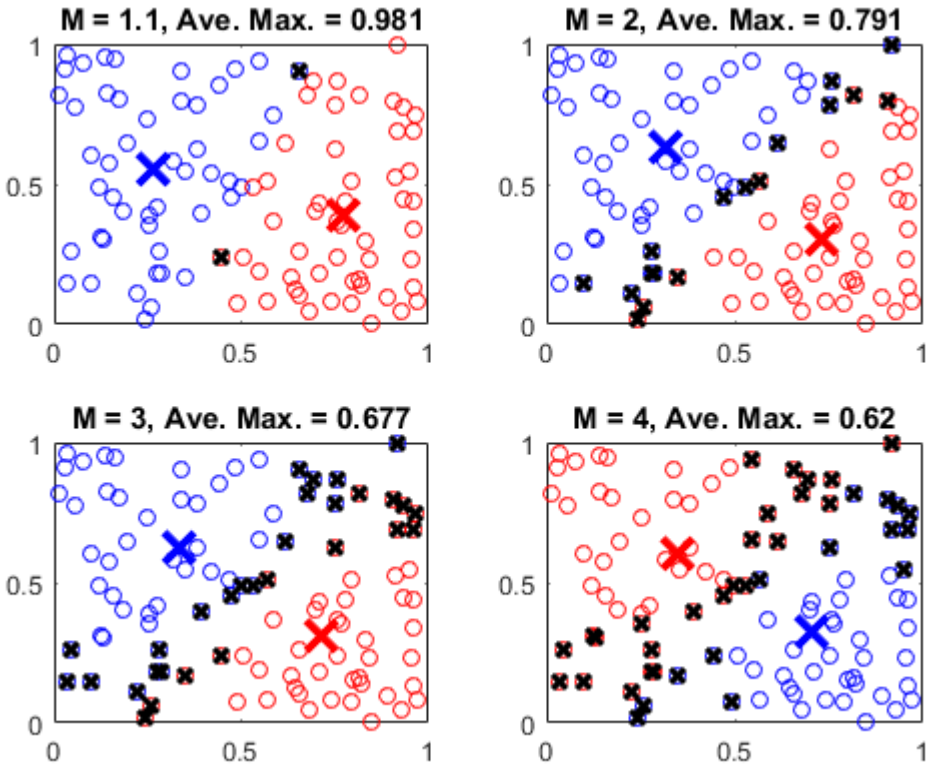


Fuzzy c-means clustering

- In **Centroid-based** clustering method, clusters are represented by a central vector.
- FCM is based on the minimization of objective function,

$$J_m = \sum_{i=1}^{D} \sum_{j=1}^{N} \mu_{ij}^{m} \|x_i - c_j\|^2$$

- Possibility, or the extent to which each data point belongs to each cluster is measured by **membership matrix**. Its element μ_{ij} means the degree of membership of *i*th point in *j*th cluster.
- *m* controls the degree of **fuzzy overlap,** which refers how fuzzy the boundaries between clusters are.



Fuzzy c-means clustering

- FCM can be performed in following iterative way.

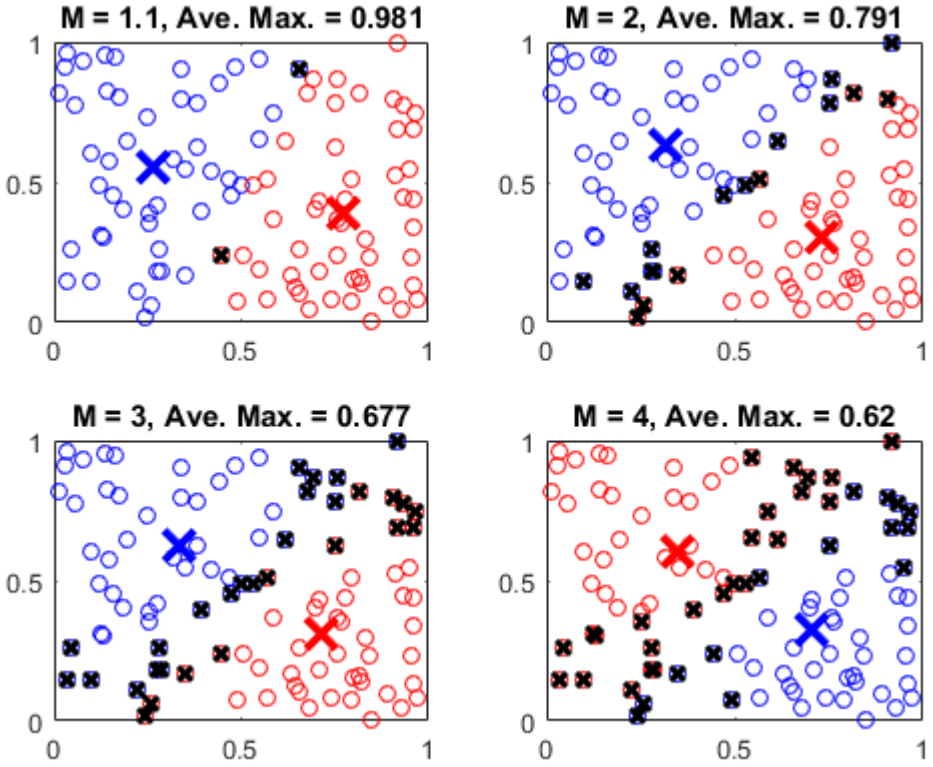
1. Randomly initialize the cluster membership values, μ_{ij}.
2. Calculate the cluster centers:

$$c_j = \frac{\sum_{i=1}^{D} \mu_{ij}^m x_i}{\sum_{i=1}^{D} \mu_{ij}^m}.$$

3. Update μ_{ij} according to the following:

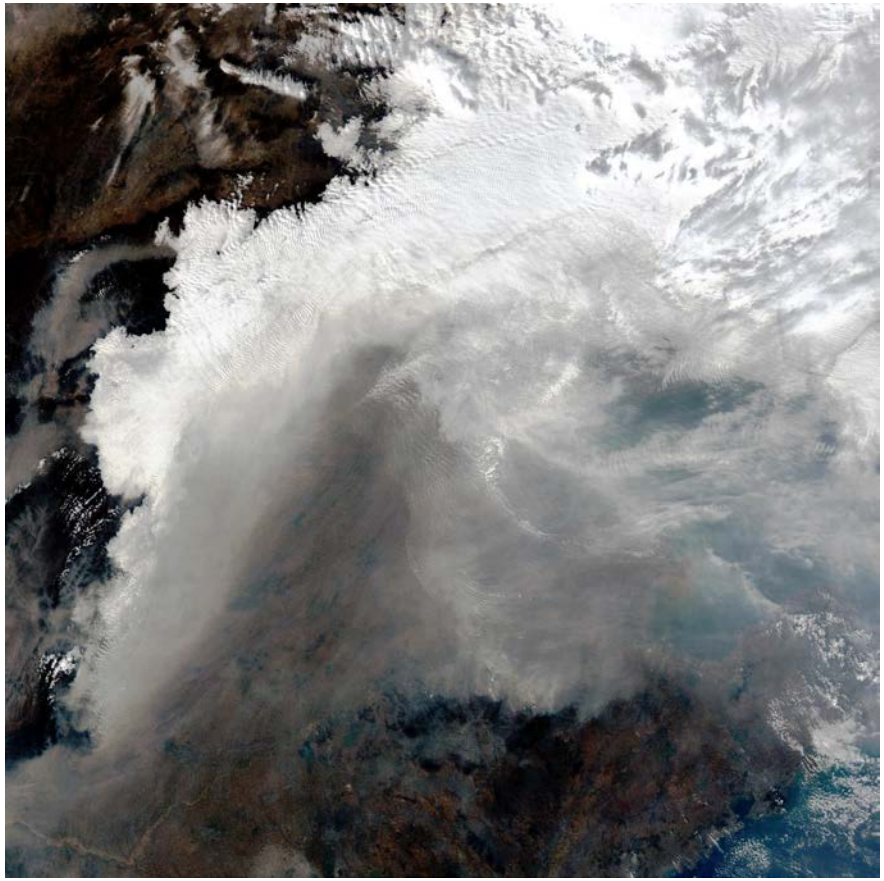
$$\mu_{ij} = \frac{1}{\sum_{k=1}^{N} \left(\frac{\|x_i - c_j\|}{\|x_i - c_k\|} \right)^{\frac{2}{m-1}}}.$$

4. Calculate the objective function, J_m.
5. Repeat steps 2–4.



Characteristics of cloud and haze

- A cloud is…
  - White
  - Opaque in visual and infrared bands
  - In high altitude
  - Rich in spatial texture, spatially rough
  - Often moving quickly
- A haze is…
  - Grey, brown, yellow
  - Semi-transparent in visual bands, transparent in infrared bands.
  - In low altitude, limited to terrain features
  - Less in spatially texture, spatially smooth
  - Often moving slowly



Characteristics of cloud and haze

- Each point is clustered according to
  - Visual bands intensity (R, G, B).
  - Thermal infrared bands (860nm, 1240nm).
  - Spatial texture in bands above.
  - Terrain feature underneath.
  - Temporal image series.

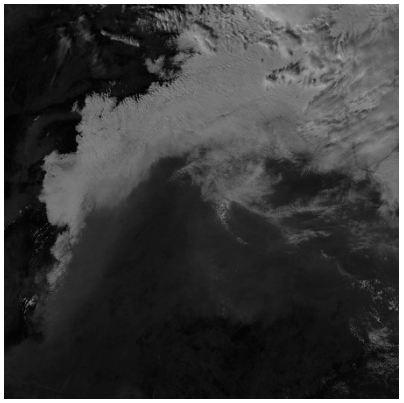
$$J_m = \sum_{i=1}^{D} \sum_{j=1}^{N} \mu_{ij}^{m} \|x_i - c_j\|^2$$

- If p features are used, each point is seen as a point in a p-dimensional space, such that

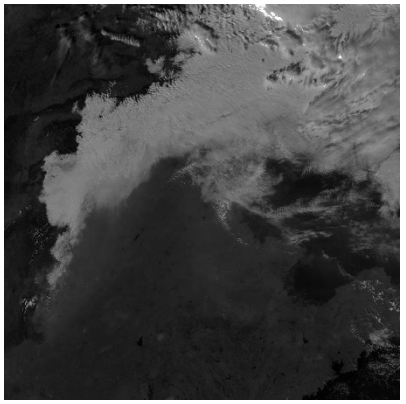
$$x_i = (R_{1i}, R_{2i}, \cdots R_{pi})$$

- Euclidean distance between 2 p-dimensional points is

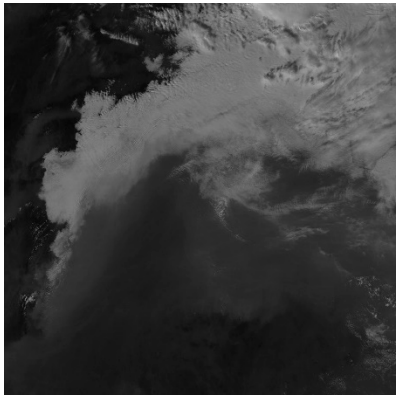
$$\|x_i - x_j\| = \sqrt{\sum_{k=1}^{p} (R_{ki} - R_{kj})^2}$$



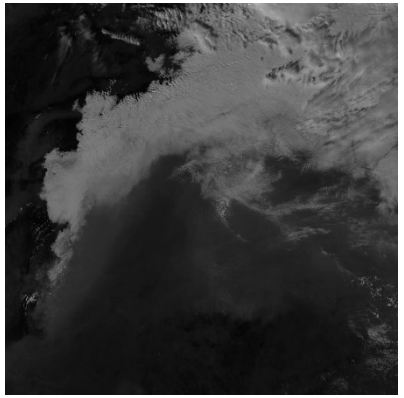
Band 1, 620-670nm, R



Band 2, 841-876nm, IR



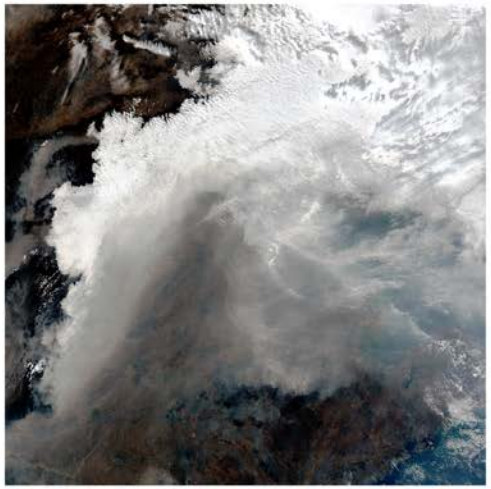
Band 3, 459-479nm, B



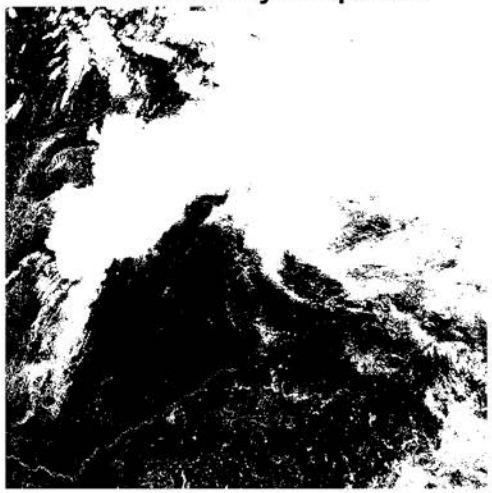
Band 4, 545-565nm, G

Cloud boundary & mask comparison

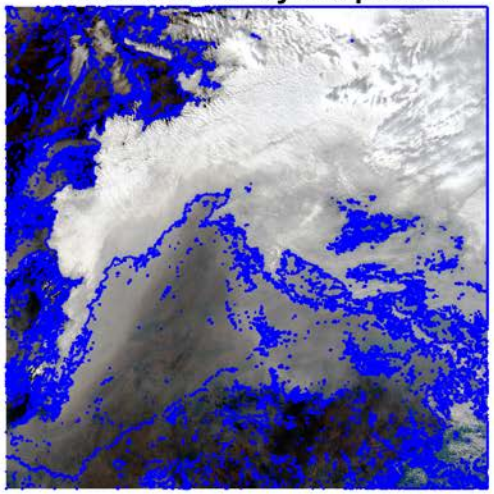
RGB scene

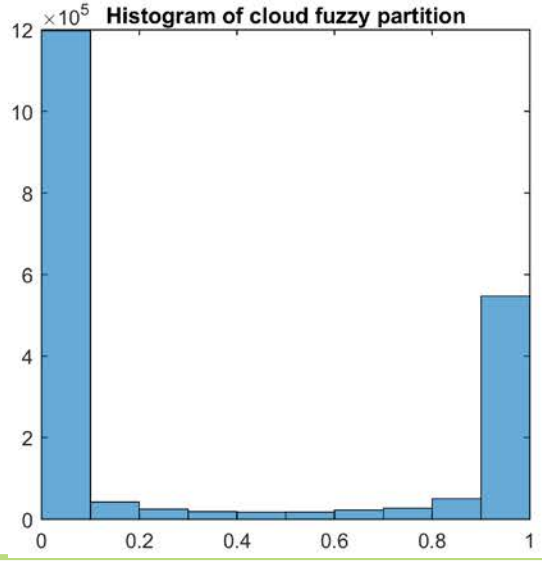


Cloud mask by Deep Blue

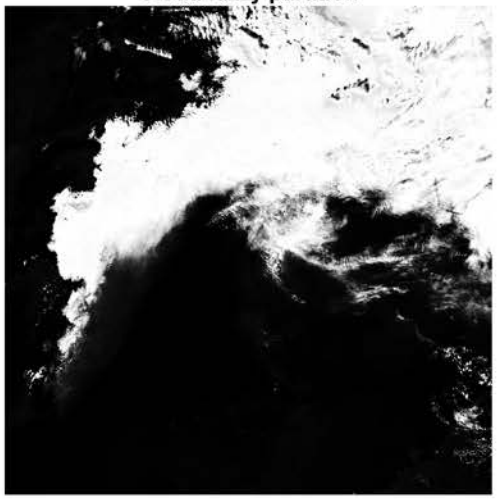


Cloud contour by Deep Blue

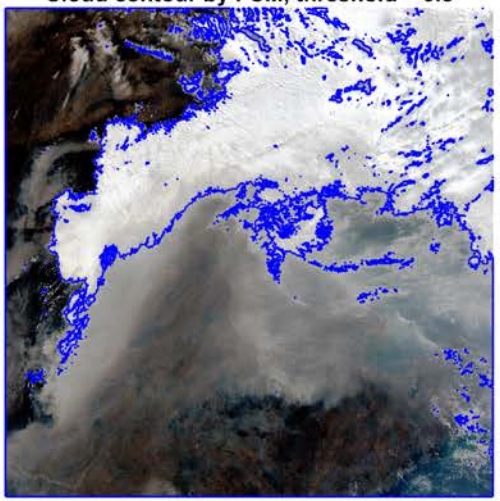




Cloud fuzzy partition

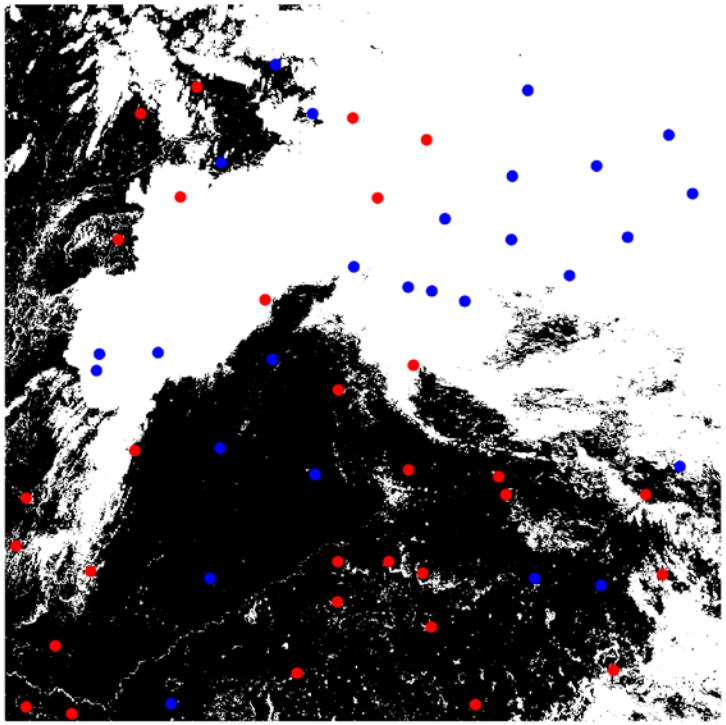


Cloud contour by FCM, threshold = 0.8



Cloud mask & surface data comparison

Cloud mask by Deep Blue
Red dots = Surface stations with RH<80% and VIS<10km. Blue dots = other stations



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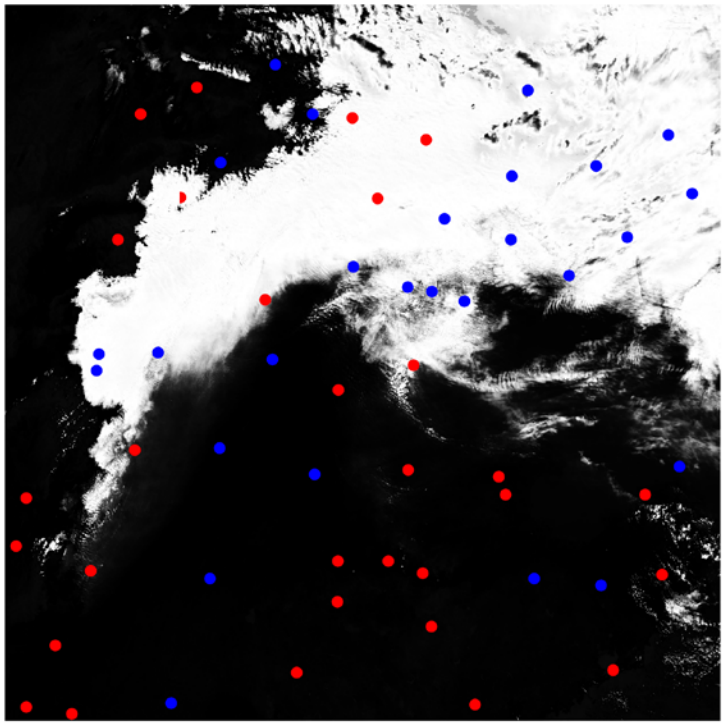
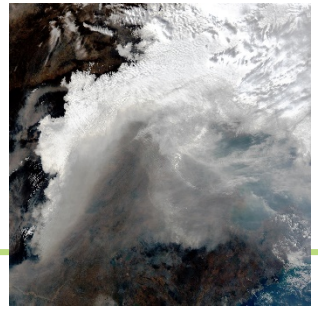
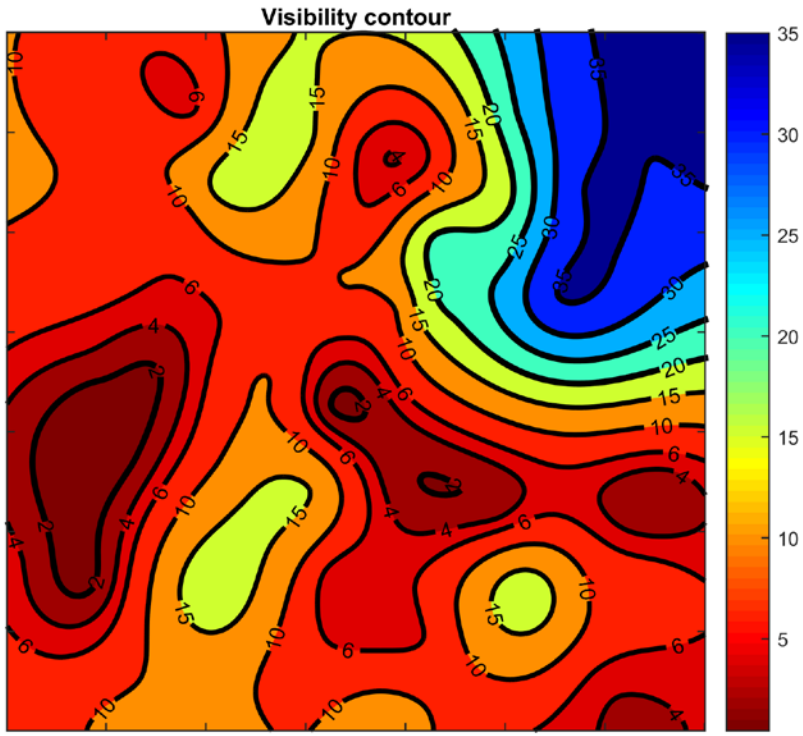
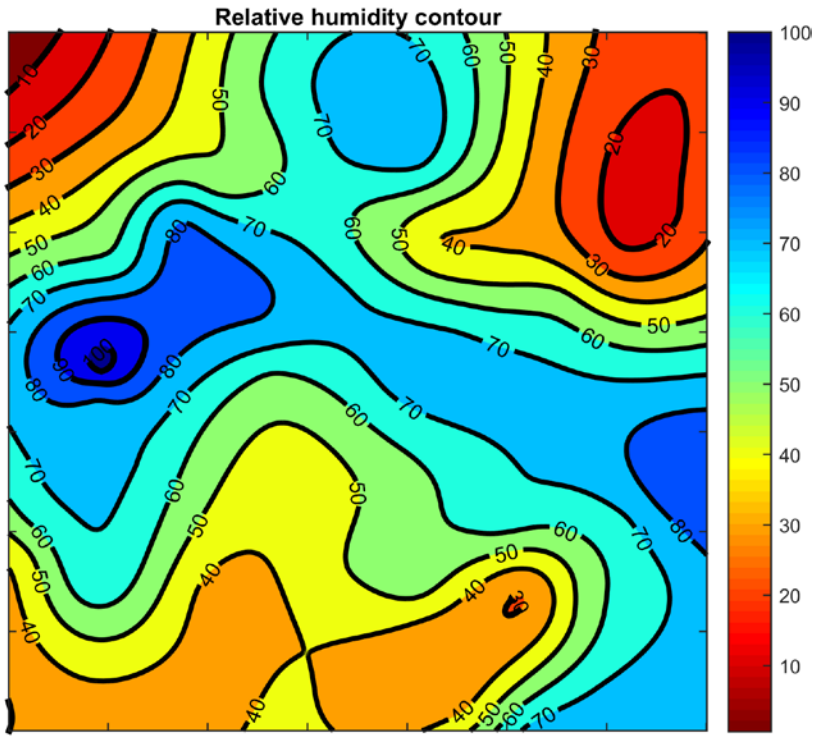
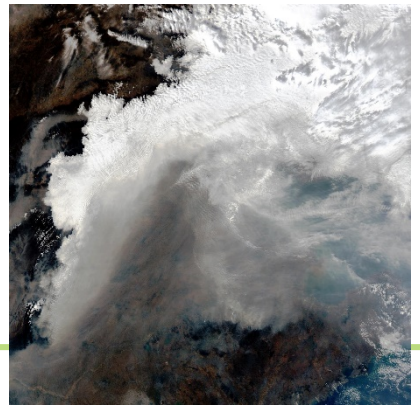


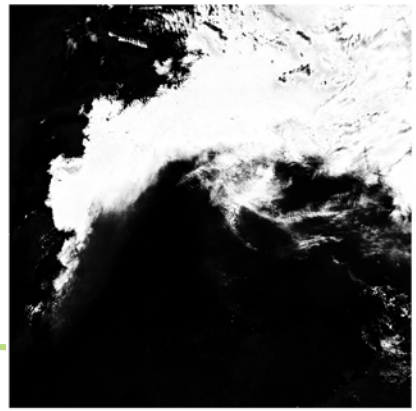


Cloud mask & surface data comparison

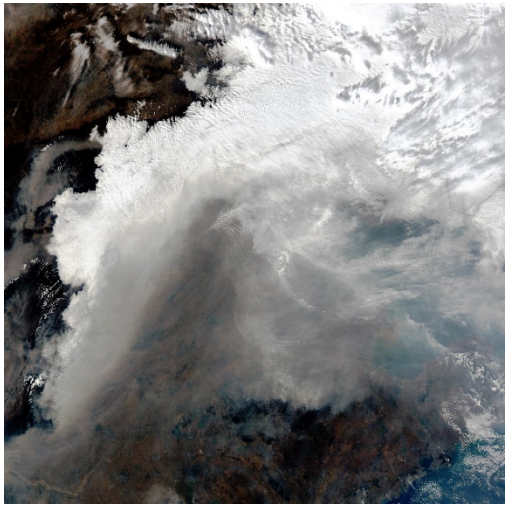


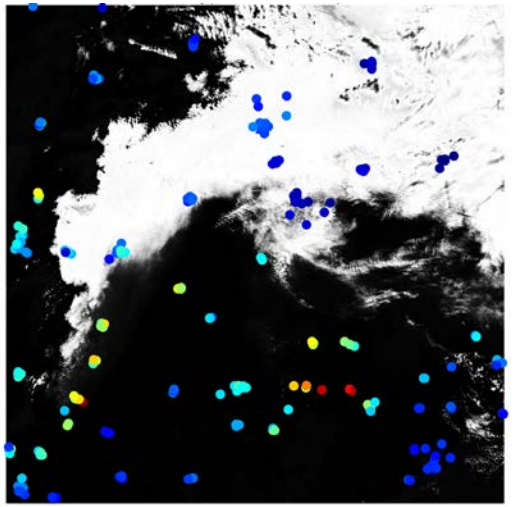


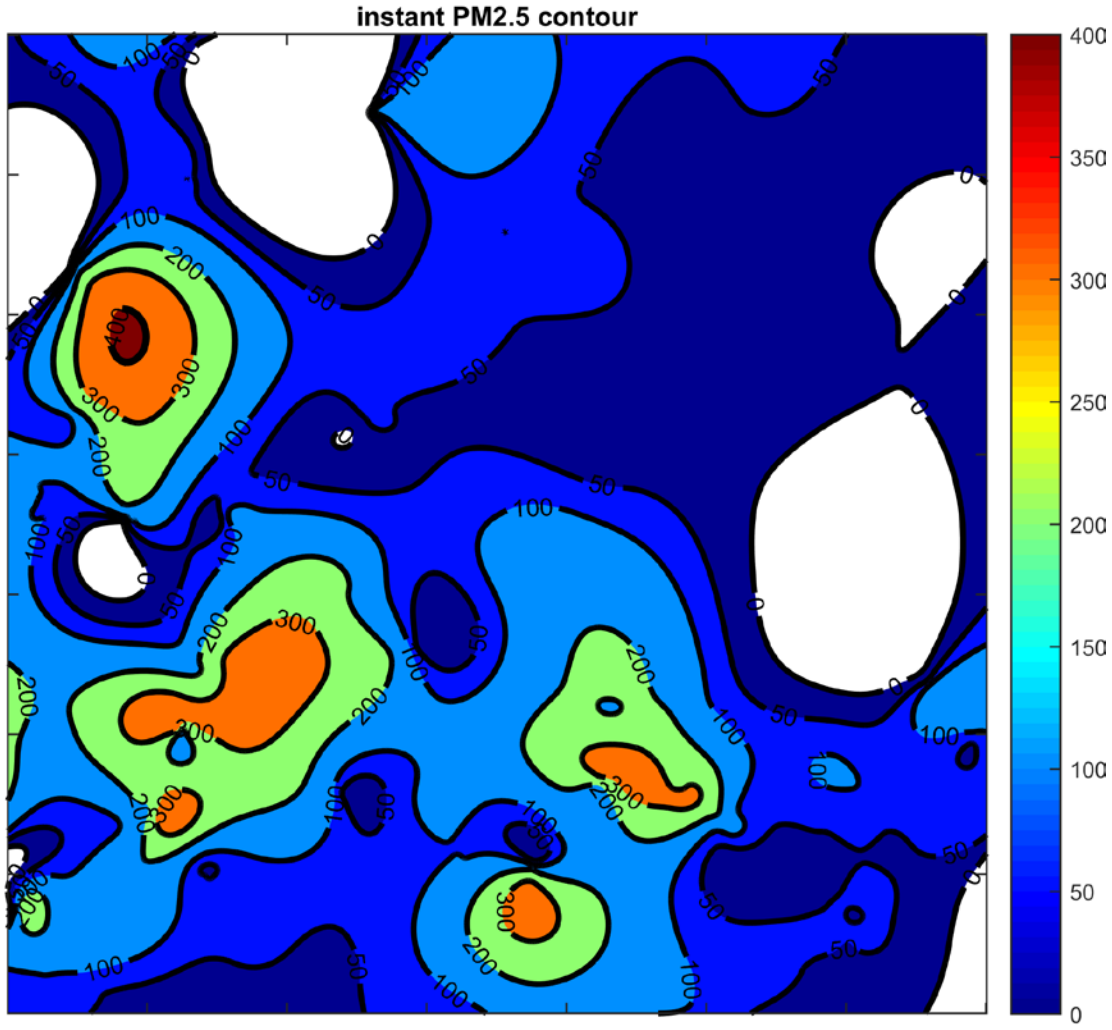




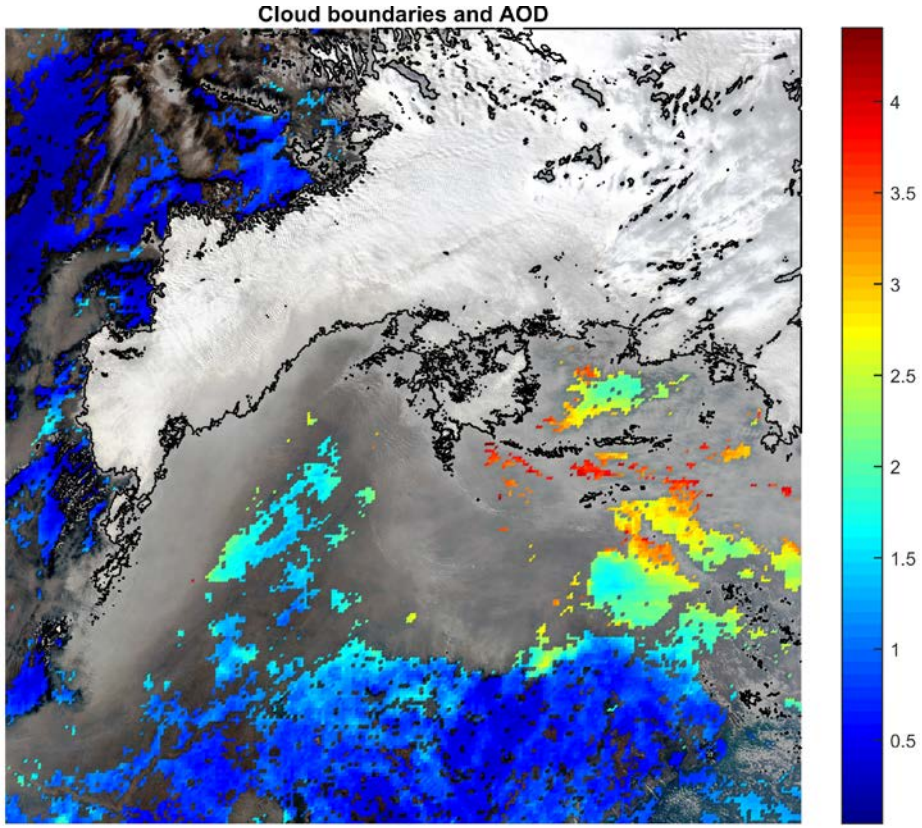
Cloud mask & pm2.5 data comparison

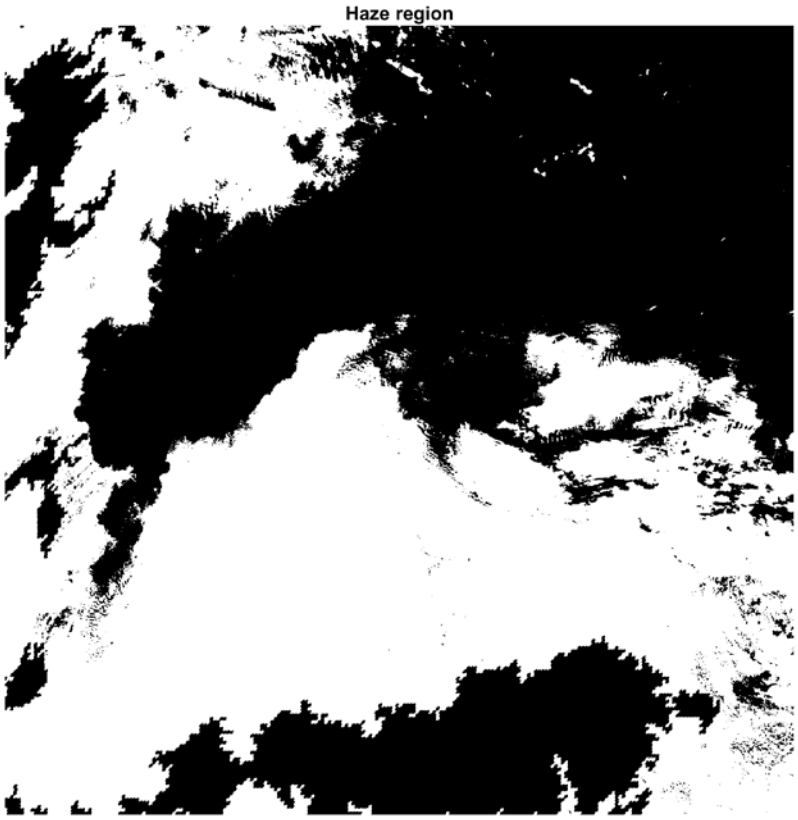






AOD data synergy and haze region





Conclusion and future work

- Fuzzy clustering method can learn from characteristics of haze region, hence distinguish haze and cloud from satellite imagery.
- Distinguishing results are plausible comparing to station & satellite auxiliary data.
- Haze region can be retrieved, filling the blank area of the nullification of AOD retrieval algorithms.

- Introduce more features to classify cloud and haze.
- Develop a systematic quantitative method for result validation.

Thank you