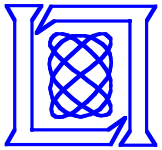


Cloud Cover Detection Algorithm for EO-1 Hyperion Imagery

Michael Griffin and Hsiao-hua Burke
MIT Lincoln Laboratory

Dan Mandl and Jerry Miller
NASA GSFC

EO-1 SVT Meeting
21 November 2002

Cloud Cover Estimation

Motivation

- To demonstrate the potential for on-board EO-1 cloud detection
  - To regulate which scenes would be transmitted for ground processing
  - Part of EO-1 Extended Mission Phase

Objective

- Produce a prototype cloud cover detection algorithm that runs on-board the EO-1 spacecraft

Methodology

- Use a small number of hyperspectral bands in a series of tests to discriminate cloud from surface features

Cloud Cover Estimation Procedure

- From calibrated Hyperion radiance data, convert to top-of atmosphere (TOA) reflectance and estimate on a pixel-by-pixel basis the extent of cloud cover in a scene.

1. Convert radiance data to TOA reflectance
   - Use pre-computed band solar flux values, earth-sun distance ratio, and the solar zenith angle
2. Process each frame (or line) of data
   - Determine which pixels are cloud-covered
   - Distinguish land, water, snow or ice from clouds
3. Produce cloud cover statistics for the scene

1. Radiance to TOA Reflectance
- *Procedure* -

- **Obtain calibrated level 1B radiance data**
  - **Large part of cloud cover effort is focused on this task**
  - **1 frame (256 samples by 6 bands) at a time**

- **Obtain from telemetry or other means for the Hyperion scene**
  - **Earth-sun distance ratio $d_{e\text{-}s}$**
  - **Cosine of the solar zenith angle μ_0**
  - **Band Solar Flux values $S_{0,i}$**

- **For each band *i* use the following formula to convert the calibrated Hyperion radiance L_i to reflectance ρ_i**

$$\rho_i = \left[\frac{\pi}{\mu_0 \, S_{0,i} / d_{e-s}^2} \right] L_i$$

- **Final product is one TOA reflectance value for each band at each pixel**
  - **$\rho(256,6)$ for a single Hyperion frame**

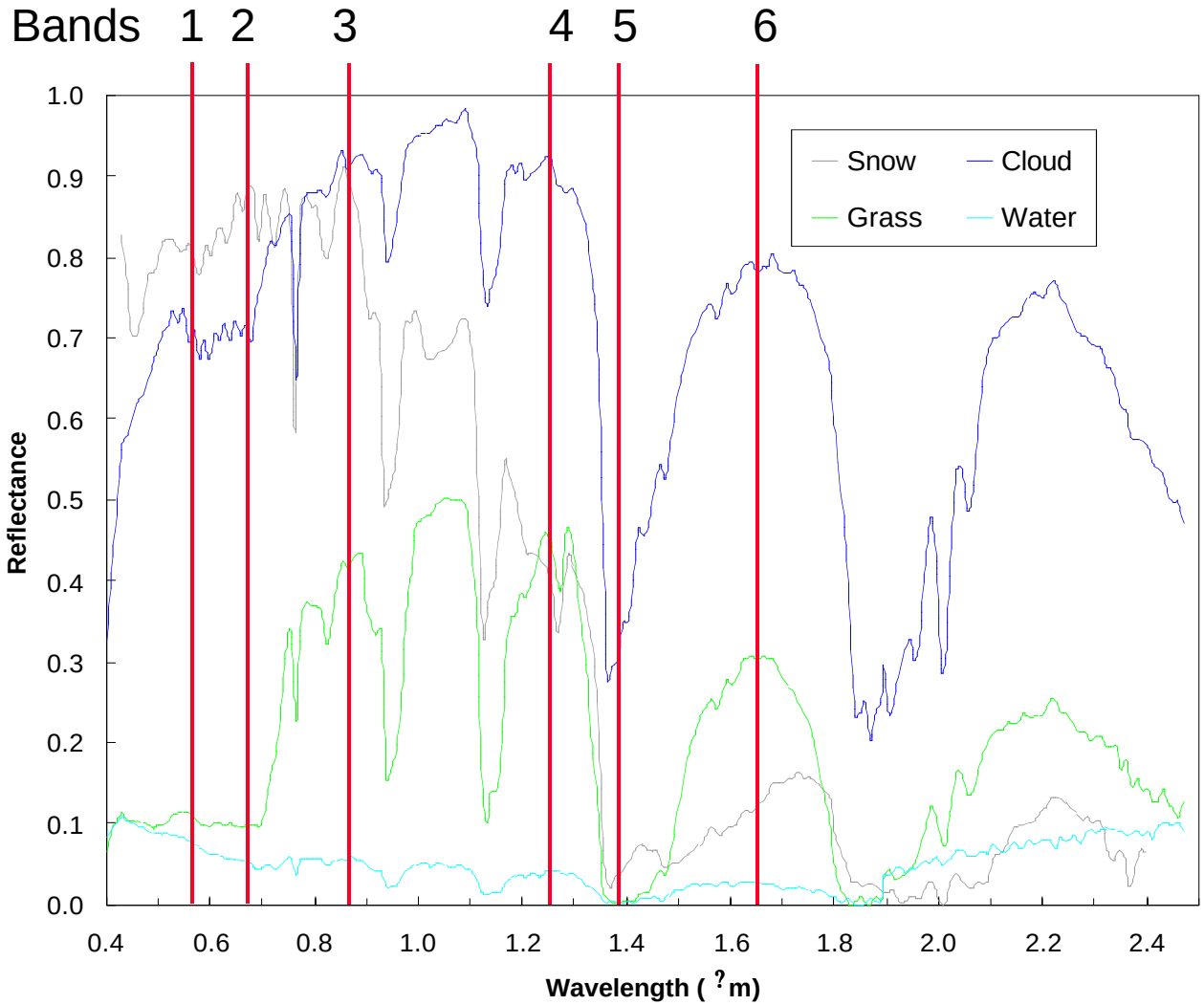
2. Cloud Cover Algorithm
- *Basic Tests* -

- **The cloud cover algorithm uses only 6 bands of Hyperion data**
  - **0.56, 0.66, 0.86, 1.25, 1.38, 1.65 μm**

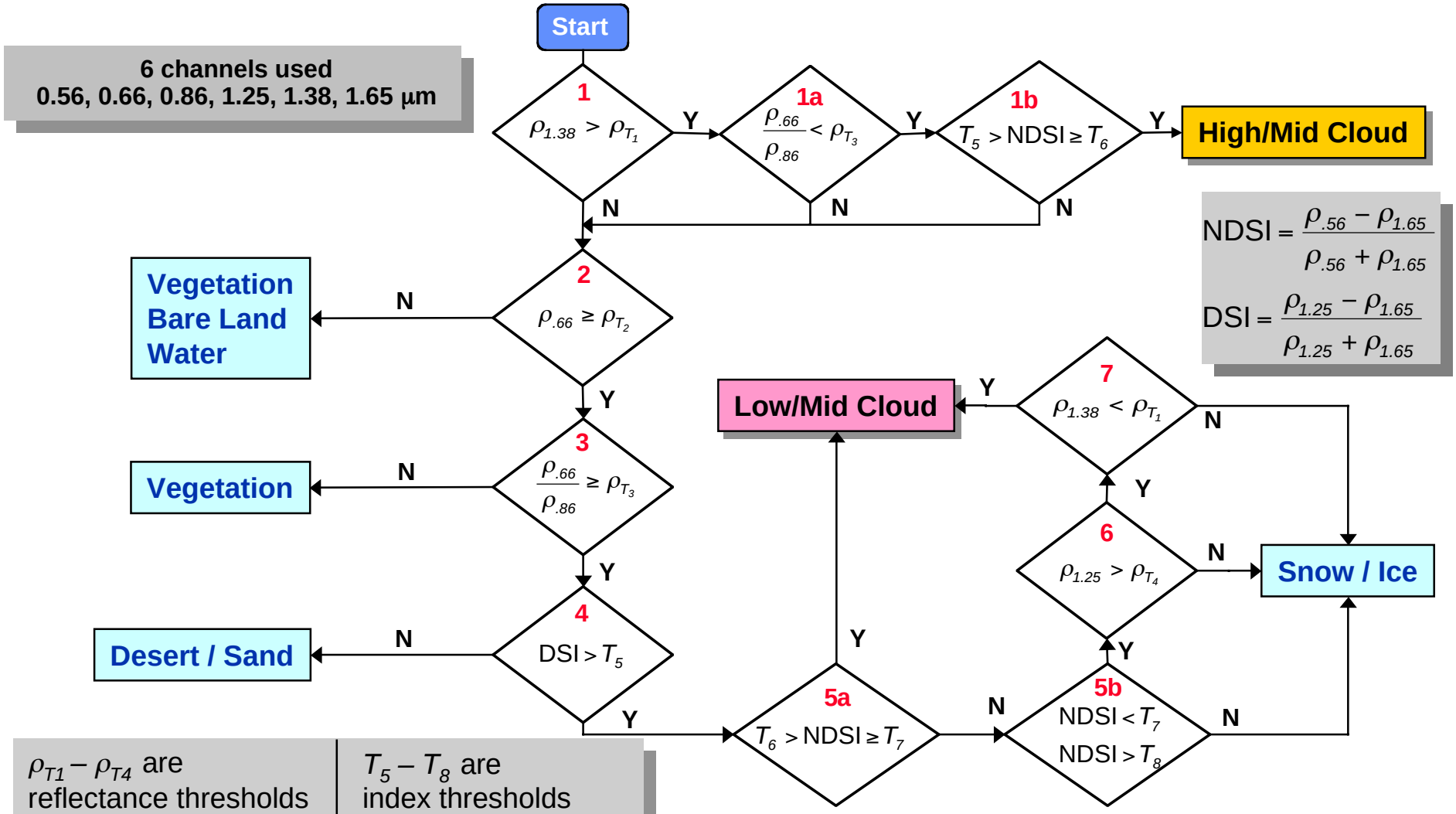
0.56 μm	**:**	**used w/ 1.65 μm to compute the snow index**
0.66 μm	**:**	**basic cloud reflectance test channel**
0.86 μm	**:**	**used w/ 0.66 μm in NDVI-like ratio test**
1.25 μm	**:**	**desert/sand discrimination**
1.38 μm	**:**	**high cloud test channel**
1.65 μm	**:**	**used w/ 0.56 μm to compute the snow index**

- **On-board processing limitations requires small number of bands**
- **Each test utilizes TOA reflectance data**
- **20 Hyperion scenes of varying surface and cloud features were used to define test thresholds**

Spectral Band Locations With Sample Reflectance Curves



Cloud Cover Detection Algorithm



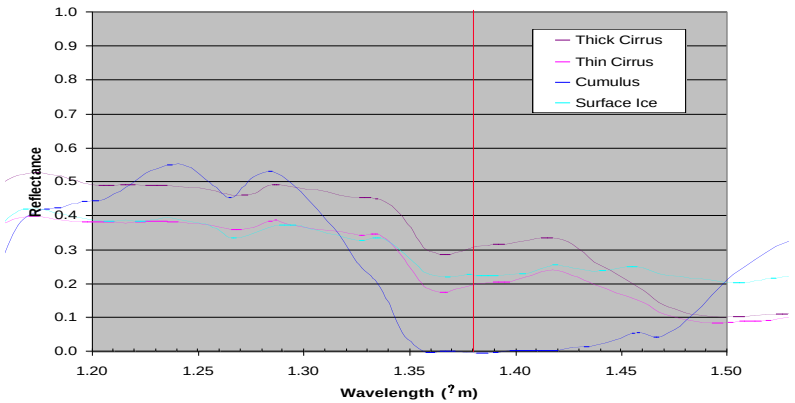
NDSI: Normalized Difference Snow Index, DSI: Desert/Sand Index

Cloud Cover Algorithm
- *NIR Absorption Band Tests* -

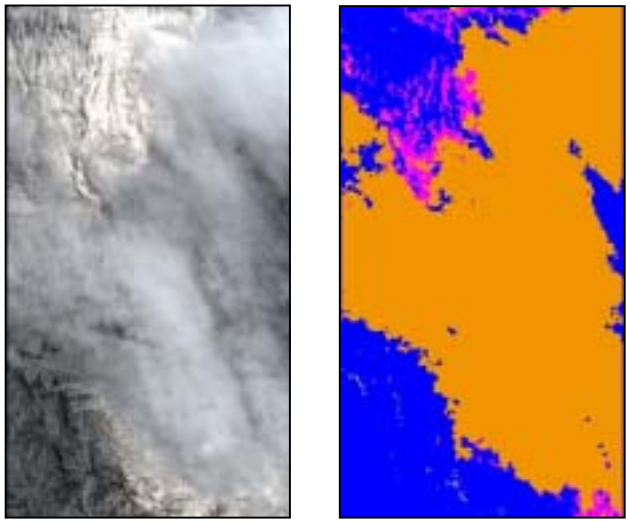
Test 1 : High/mid cloud reflectance threshold

$$\rho_{1.38\ \mu m} > \sim 0.1$$

- Only high clouds are typically observed in this channel
- Strong water vapor absorption masks most low level/surface features
- Under dry conditions, surface features such as ice and snow can be observed and mistaken for clouds
- Further vegetation and snow/ice discrimination tests are necessary to isolate clouds



Cheyenne Wyoming



Cloud-free, Low/**Mid** cloud, **Mid/High cloud**

No (N)	Yes (Y)
All others	High/Mid Clouds

To Test 2

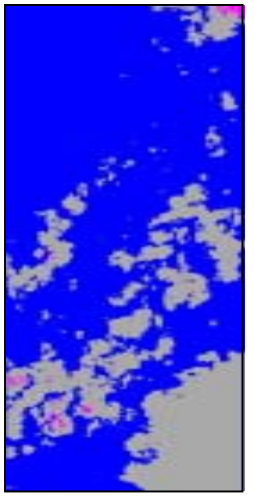
2. Cloud Cover Algorithm
- *Visible Reflectance Test* -

Test 2 : Red channel reflectance threshold

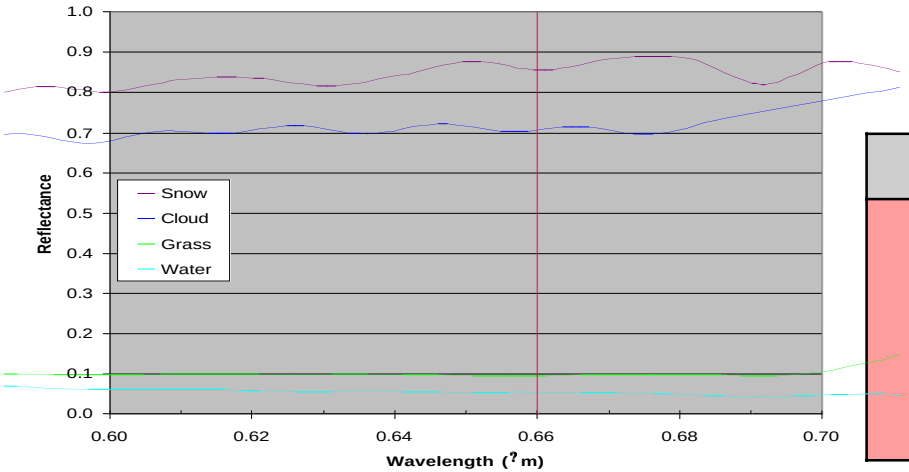
$$\rho_{0.66\ \mu m} > \sim 0.3$$

- Assumes low reflectance of most vegetation, soil and water surfaces in the red region of the spectrum
- Snow, Ice, bright desert/sand surfaces and clouds should pass this test

Kokee Hawaii



Cloud-free Low/**Mid** cloud



No (N)	Yes (Y)
Vegetation Soil Water	Snow / Ice Desert / Sand Some Vegetation Clouds

To Test 3

2. Cloud Cover Algorithm
- *Visible/NIR Ratio Test* -

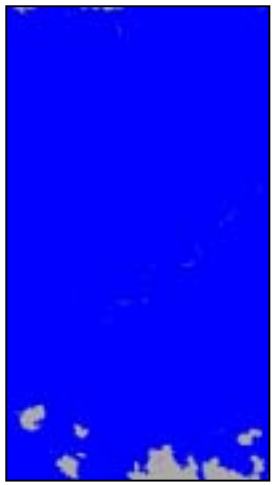
Test 3 : VIS/NIR ratio test

$$\rho_{0.66\ \mu m} / \rho_{0.86\ \mu m} > \sim 0.7$$

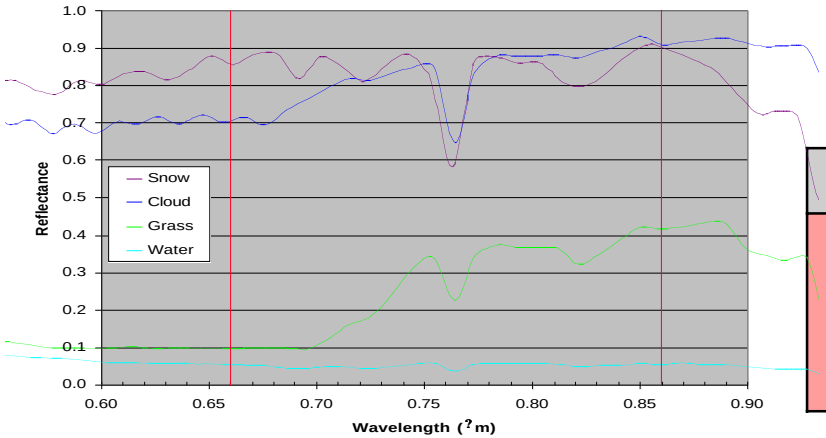
- Discriminates vegetative surfaces whose reflectance varies strongly from Visible to NIR
- Vegetative and soil surfaces exhibit small ratio values.
- Clouds, desert/sand, snow and ice surfaces have high ratio values

Kokee Hawaii

Cloud-free



Low/Mid cloud



No (N)	Yes (Y)
Vegetation	Snow / Ice Desert / Sand Clouds

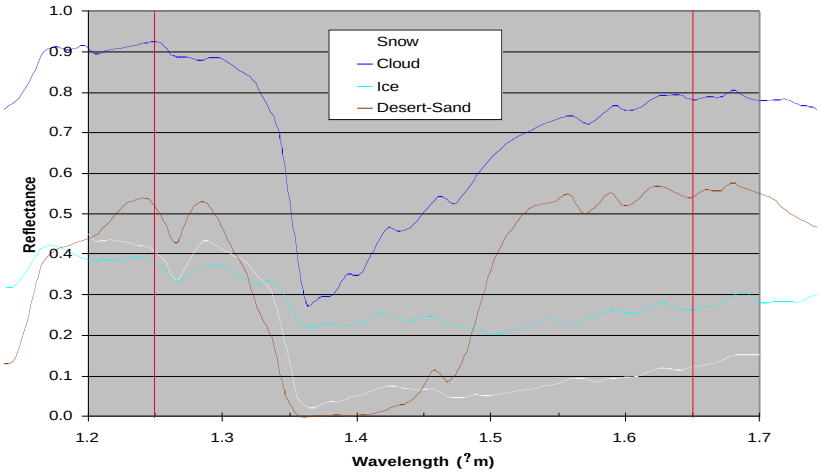
To Test 4

2. Cloud Cover Algorithm
- *Bright Desert/Sand* -

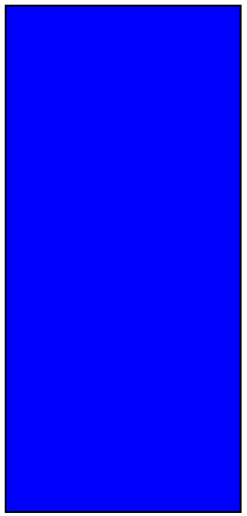
Test 4 : Desert Sand Index (DSI)

$$DSI = \frac{\rho_{1.25} - \rho_{1.65}}{\rho_{1.25} + \rho_{1.65}} > -0.01$$

- Discriminates bright soil and sand surfaces whose reflectance increases slightly from 1.25 to 1.65 μm
- Clouds, snow and ice reflectance tends to decrease over this range

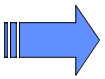


Suez Canal



Cloud-free

No (N)	Yes (Y)
Desert Sand Bright Soil	Snow / Ice Clouds



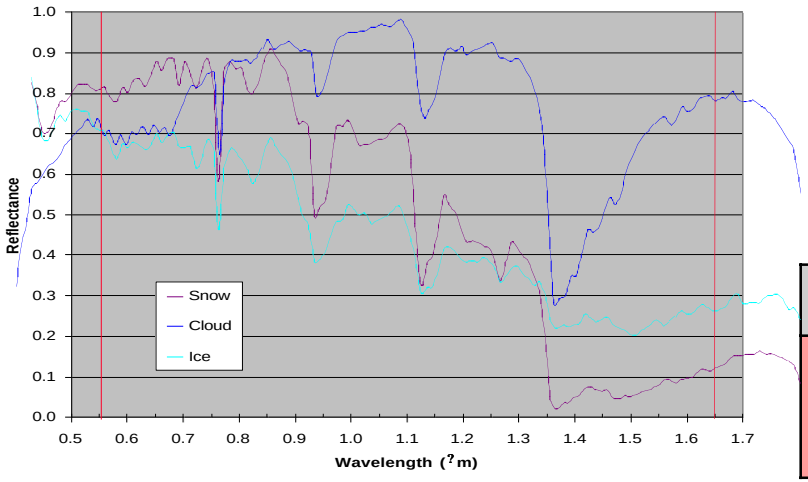
To Test 5

Cloud Cover Algorithm
- *SWIR Snow/ice/cloud Test* -

Test 5 : Normalized Difference Snow Index (NDSI)

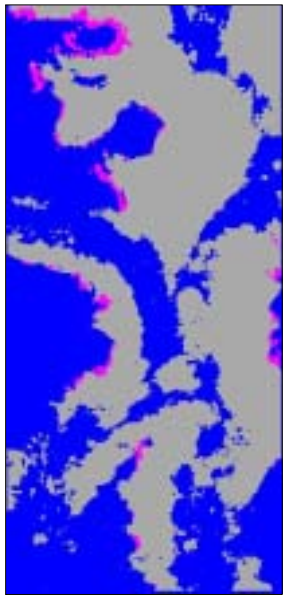
$$NDSI = \frac{\rho_{0.56\,\mu m} - \rho_{1.65\,\mu m}}{\rho_{0.56\,\mu m} + \rho_{1.65\,\mu m}}$$

- Some sparse or shadowed snow (in mountains) can pass test
- Cloud-free snow generally displays NDSI > 0.4



Sullivan Bay

Cloud-free



Low/Mid cloud

No (N)	Yes (Y)
Snow / Ice	Low / Mid Clouds Dark Snow

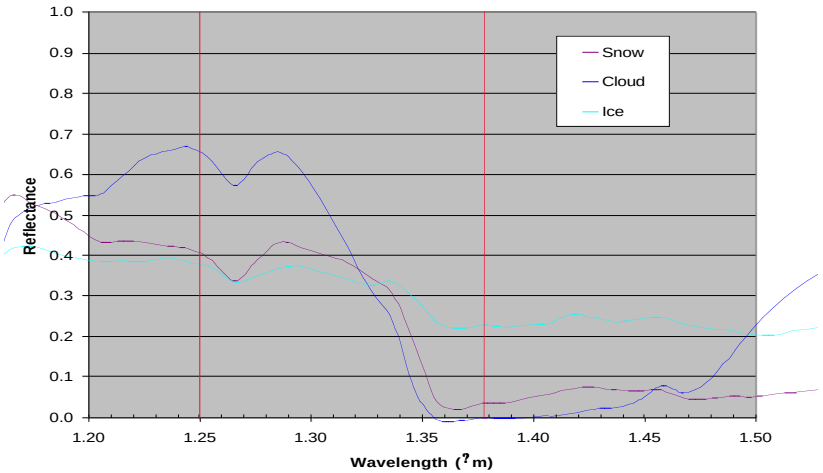
To Test 6

Cloud Cover Algorithm
- *SWIR Reflectance Tests* -

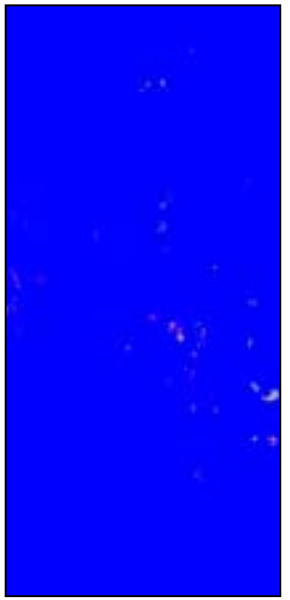
SWIR Reflectance Tests

- Test 6 $\rho_{1.25\ \mu m} > \sim 0.35$
- Test 7 $\rho_{1.38\ \mu m} < \sim 0.1$

- Eliminates most snow/ice
- Low/Mid clouds should pass tests



Bering Sea



Cloud-free Low/Mid cloud

No (N)	Yes (Y)
Snow / Ice	Low / Mid Clouds

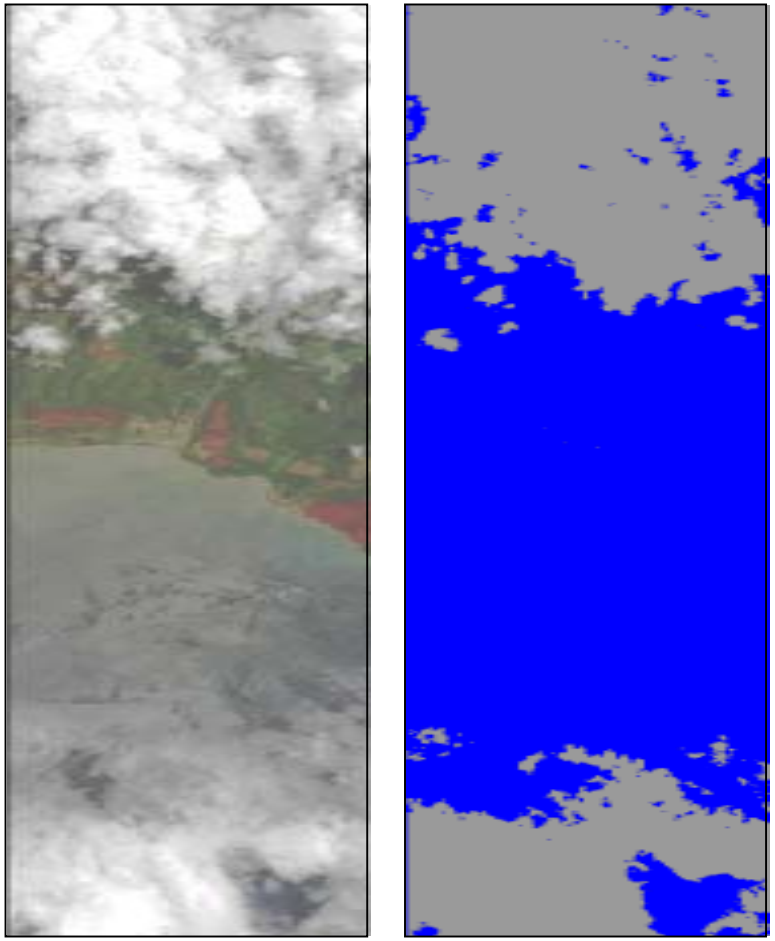
Cloud Cover Algorithm
- Test Case Results -

- The following slides show results from the cloud cover algorithm for a selection of Hyperion scenes
- One or two segments (1000 lines each) of the overall Hyperion scene are displayed
- Cloud cover estimates (percent of displayed scene covered by all clouds) is shown at the bottom
- Examples are meant to highlight successes and failures of algorithm

Colors
Cloud-free
Low/Mid cloud
Mid/High cloud

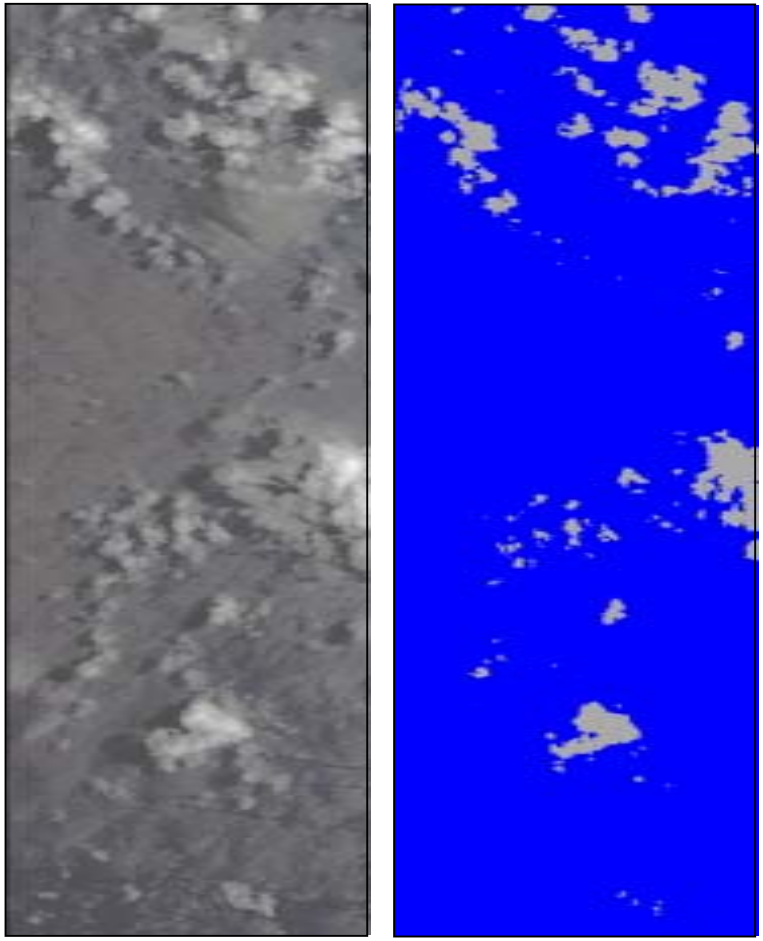
Kokee Hawaii

Lines 1700 - 2700



Total Cloud: 41.3 %

Lines 3200 - 4200

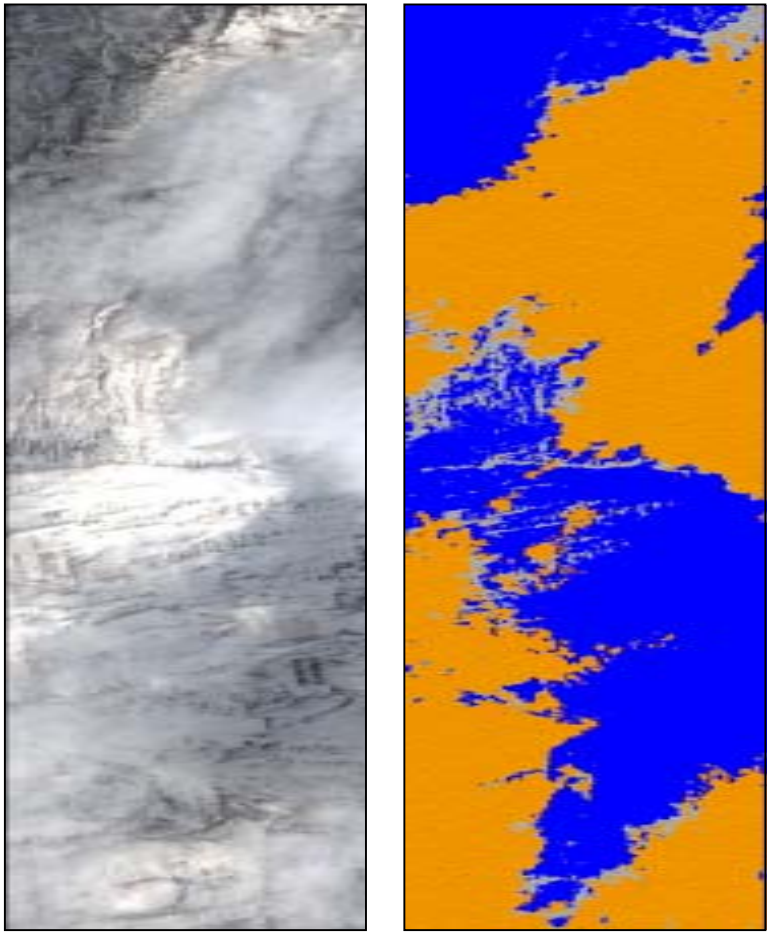


Total Cloud: 6.8 %

Success	Discriminates land/cloud, land/water
Failure	Misses some darker cloud over water

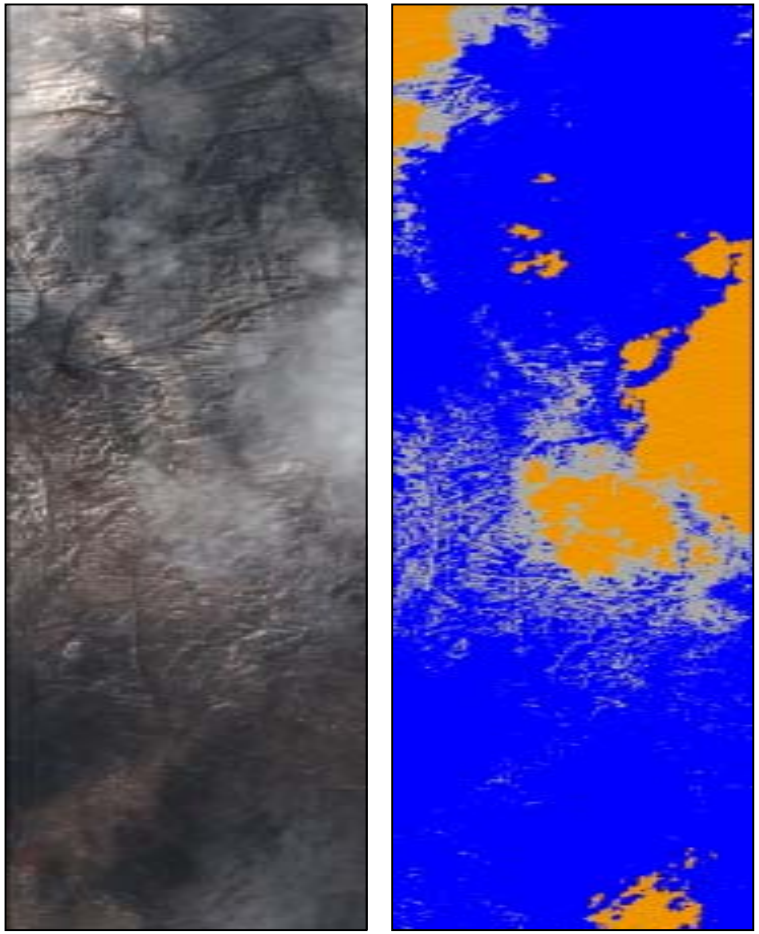
Cheyenne Wyoming

Lines 500 - 1500



Total Cloud: 58.9 %

Lines 2000 - 3000

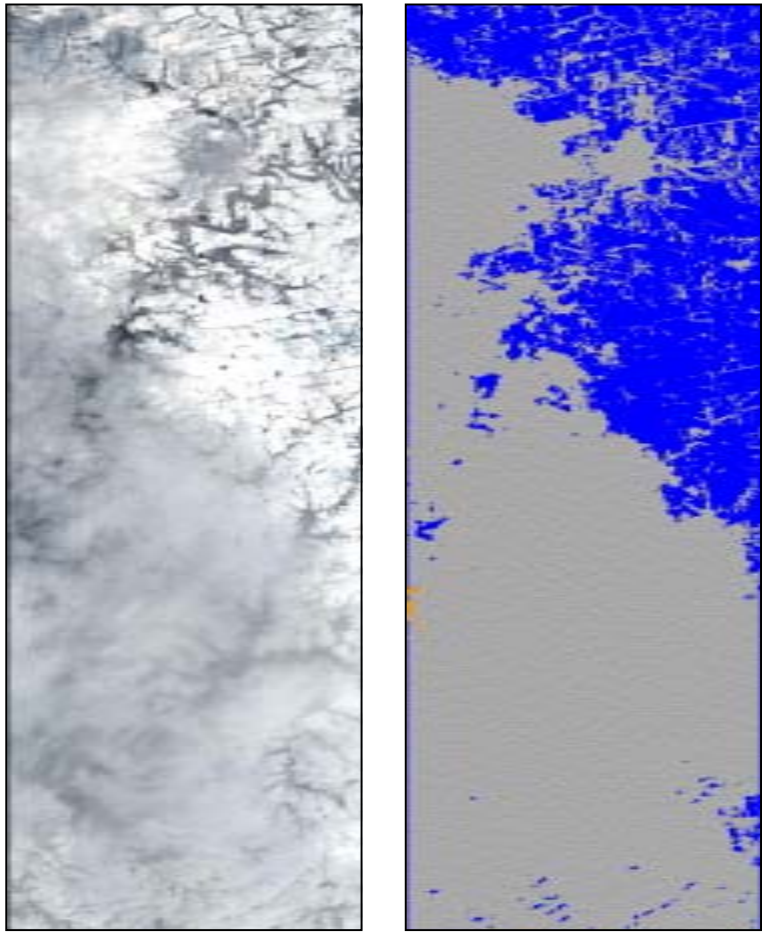


Total Cloud: 27.0 %

Success	Snow/cloud, ice cloud
Failure	Difficulty with shadowed snow cover

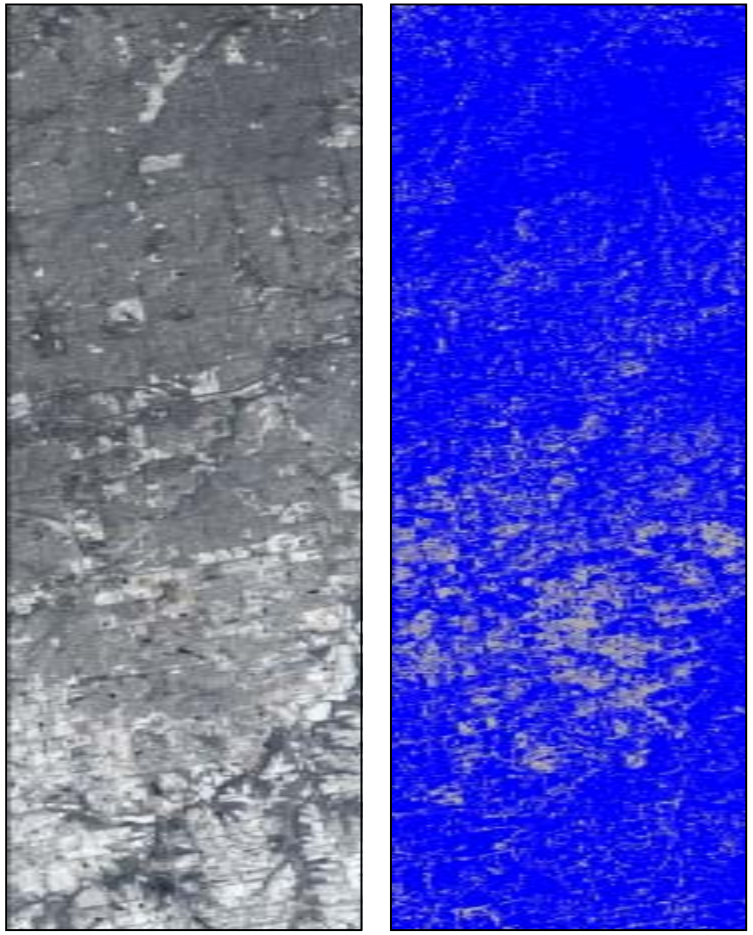
Kansas City

Lines 0 - 1000



Total Cloud: 72.6 %

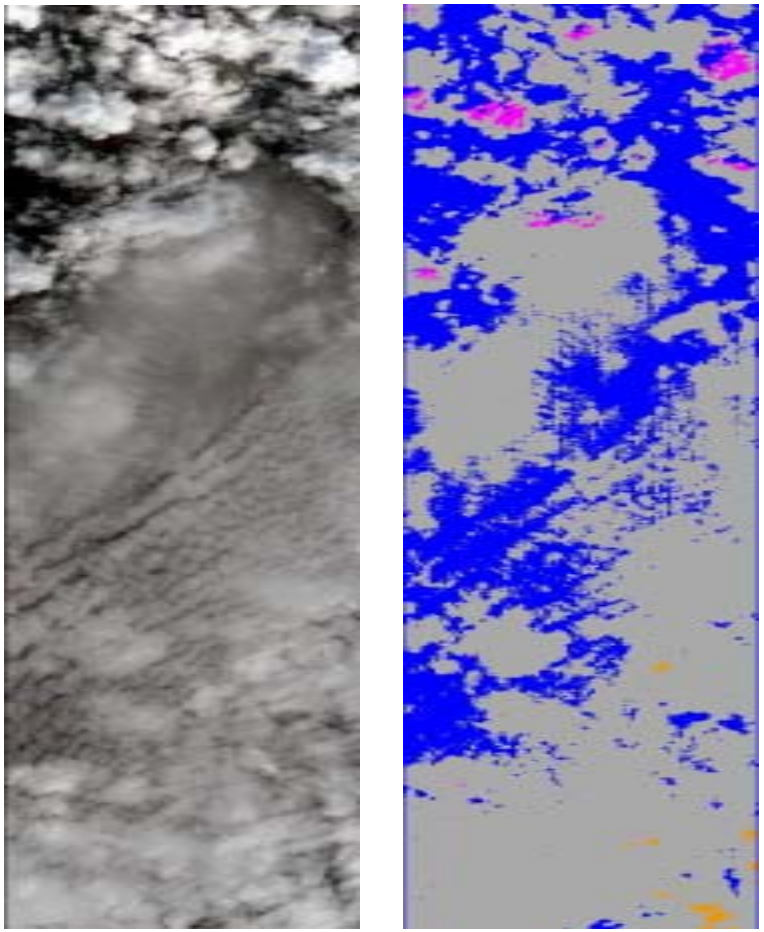
Lines 2100 - 3100



Total Cloud: 18.6 %

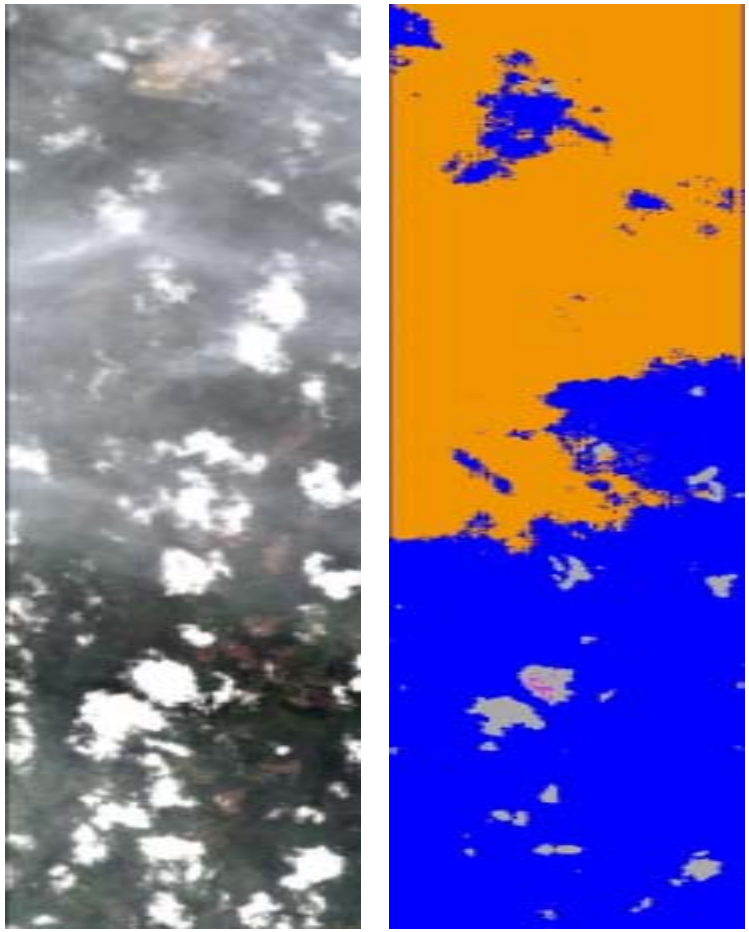
Success	Bright Snow/cloud discrimination
Failure	Some snow cover flagged as cloud

Chiefs Island



Total Cloud: 68.9 %

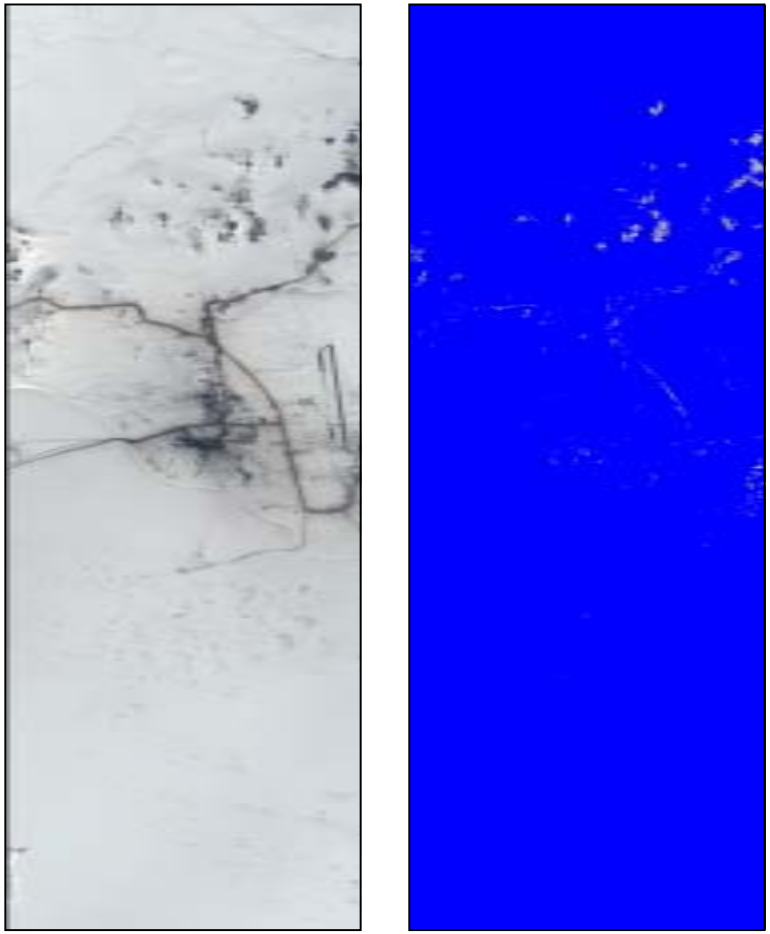
Lake Pontchartrain



Total Cloud: 48.6 %

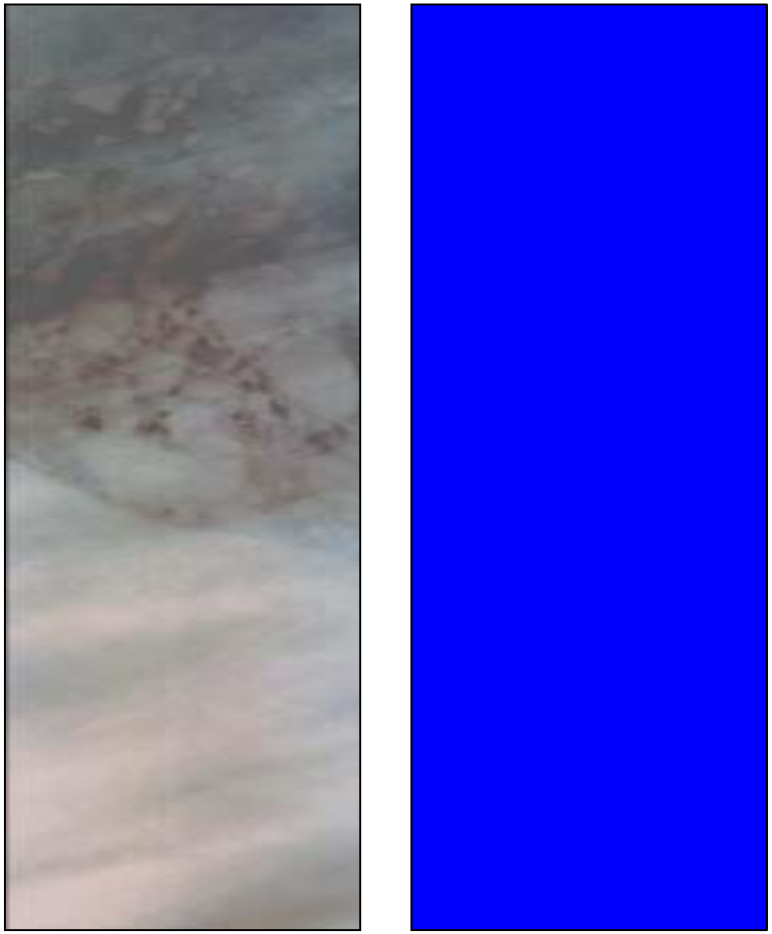
Success	Detects Cirrus, Cumulus
Failure	Cloud Cover underestimated

Bering Sea



Total Cloud: 0.7 %

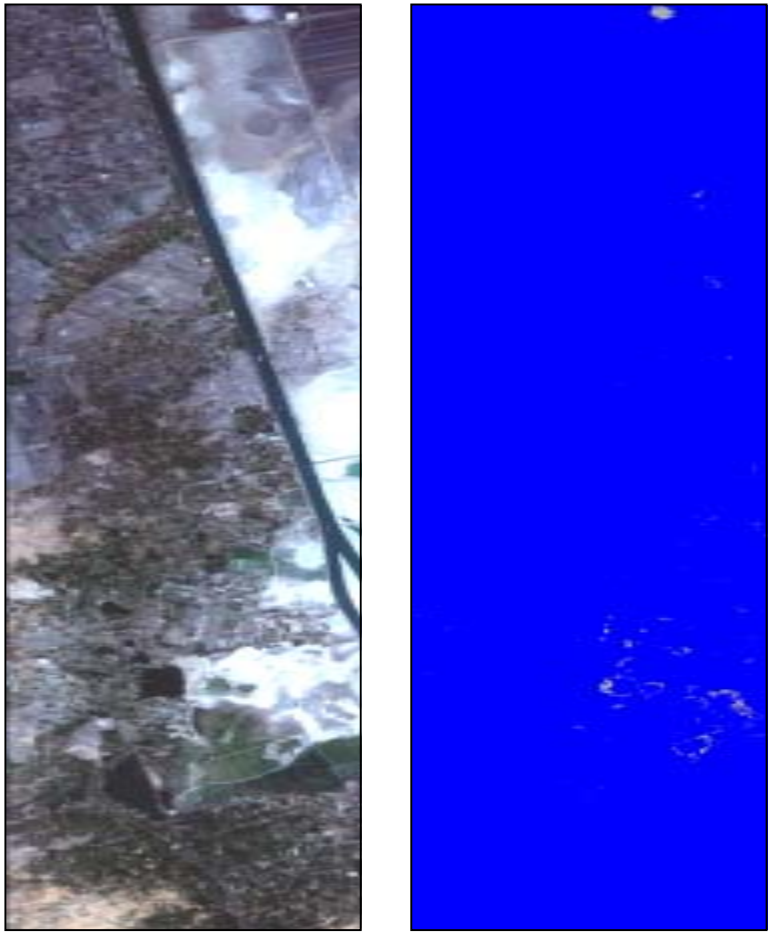
Larsen Ice Shelf



Total Cloud: 0.0 %

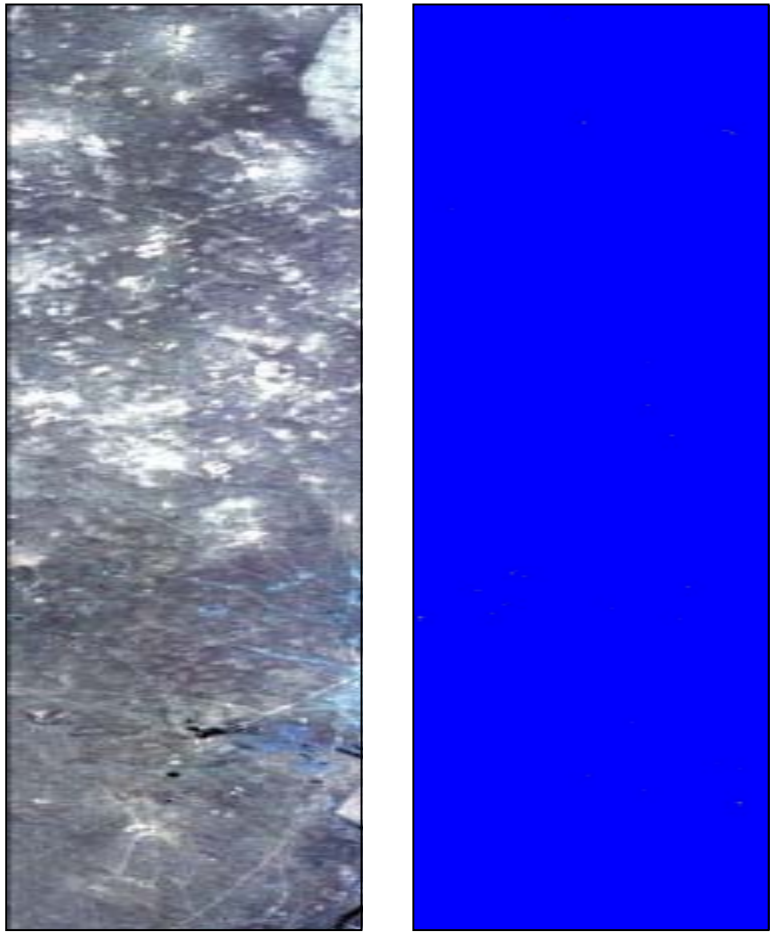
Success	Bright Ice, snow all flagged clear
Failure	Small amount of dark snow features

Suez Canal



Total Cloud: 0.3 %

Chernobyl



Total Cloud: 0.0 %

Success	Bright sand, soil all flagged clear
Failure	Small amount of bright soil

Summary of Cloud Cover Tests

Schedule calls for first on-board test in December 2002

- Algorithm results are encouraging
- On-board cloud cover detection accuracy requirements are not stringent (10-15 %)
  - Only need to know if scene is clear enough for user
  - Simple algorithms with limited # of bands sufficient
- Algorithm does a good job not classifying bright surface features (snow, ice, sand) as clouds
- Difficulties with dark snow and dark/shadowed features
  - Adjustment of thresholds (e.g., geographical, seasonal) may improve results
- Areas for future enhancements/improvements
  - More sophisticated algorithms
  - More bands
  - Validation (?)