

Supplemental materials for Wind, Porter and Liljedahl “Automated VNIR-only Cloud Detection for the WorldView Series and Similar Spacecraft”

Problem example in Landsat cloud mask

Landsat cloud mask has at times proven to be problematic even for scenes consisting of thick clouds over a dark ocean surface without sun glint. Such a scene would not be considered complex even if no spectral channels other than the basic set of 470, 550 and 650nm are available. We illustrate this using an example scene of the kind we encountered while supporting an airborne field campaign. The field campaign staff was interested in testing out the then-new capability of performing MODIS-like cloud microphysics retrievals on Landsat. We ended up adding a regional correction to the cloud mask provided by the Landsat team. Figure S1 shows such a situation using a Landsat scene acquired on 09.06.2019 at 02:36:10 UTC just east of the Philippines. Significant portions of the brightest parts of this cloud field are not being detected as cloud.

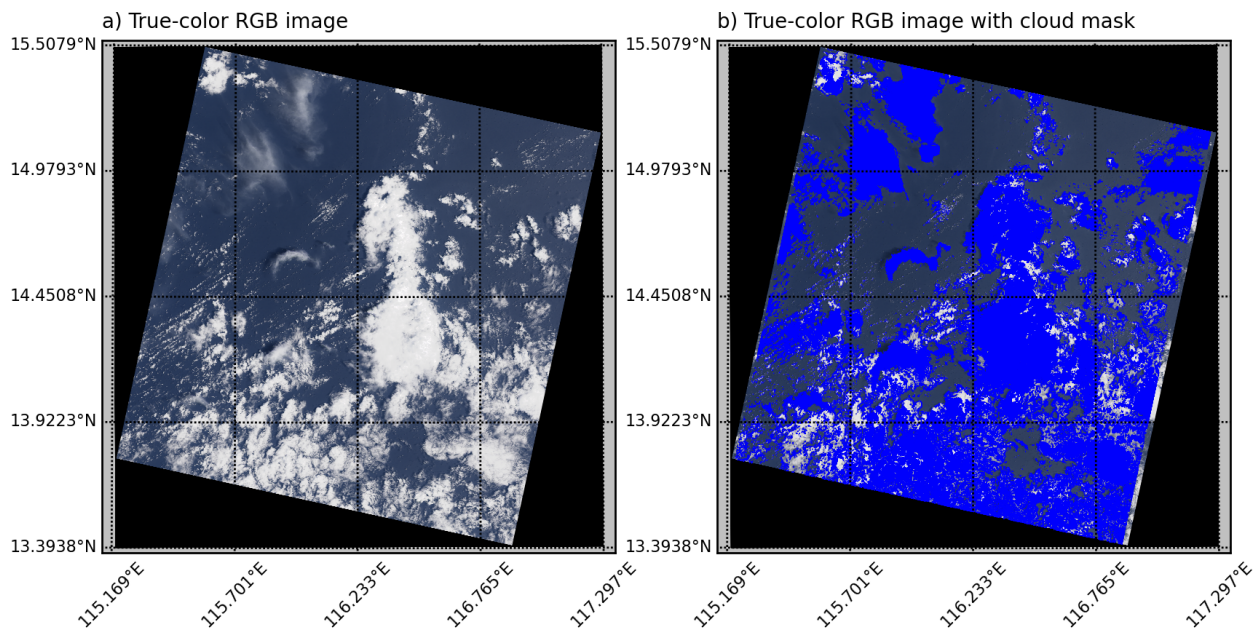
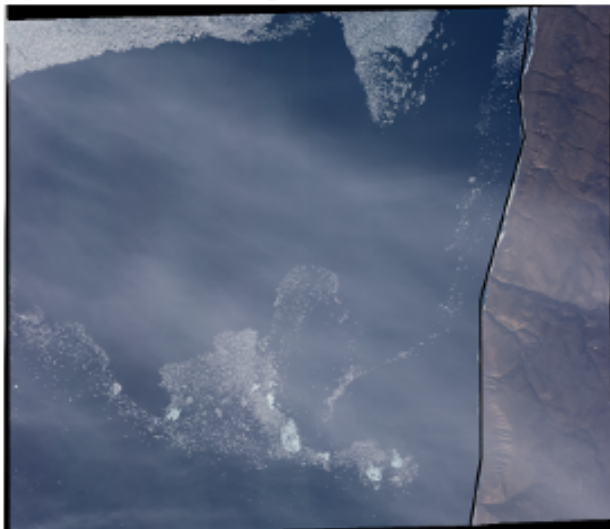


Figure S1: Landsat-8 OLI granule acquired 09.06.2019 at 02:36:10 UTC. Panel a) shows the true-color RGB image of a cloudy scene over sunglint-free dark ocean. Panel b) shows the cloud mask (blue) overlaying RGB image from panel a). White areas visible in panel b) are the clouds that failed detection.

CM-URSI for thin-cloud and sea ice mapping, incl. thin-clouds overlaying sea ice

We also mention in the text that it appears CM-URSI individual test ID results may have additional uses besides identifying clouds. Our initial finding is that the test for high dispersion (CM-URSI ID = -15) when seen over ocean surface appears to identify sea ice even in the presence of a significant cloud cover. Much more study on this would be needed and much more data would need processing in order to fully confirm this. But, if confirmed, this result could open up a large number of WorldView scenes for use by the sea ice community that would have been previously discarded. In addition to having the cloud mask identify clouds present in the scene, a sea ice fraction could also be extracted from scenes like this one.

a) True-color RGB image



b) CM-URSI test ID map

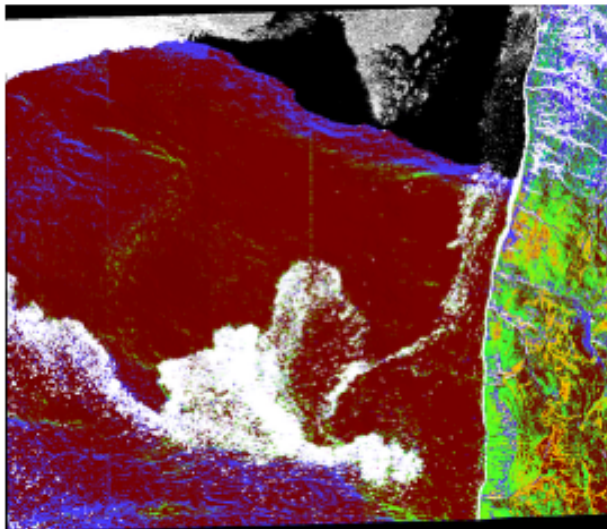


Figure S2: WorldView-3 scene 104001009A456B00 acquired on 08.07.2024 at 19:47:12 UTC. Panel a) shows the true-color RGB image of the scene. Panel b) shows the CM-URSI test map for this scene. ID values of -15 are indicated in white. When encountered over ocean these values appear to correspond with significant precision to location of sea ice.

WorldView scenes used in the study

Our text describes a set of scenes that were used to build the statistical curves used by CM-URSI. These scenes were selected on the basis of being representative and challenging at the same time. Representative so that the necessary sets of like pixels could be easily selected from various areas. Challenging because the overall scenes presented a varied background that would be good to test the full scene classification on. Table S1 lists the scenes that we used. Scenes that have two IDs listed had both VNIR and SWIR acquisitions available to us. Whereas having SWIR channels on hand was useful in selecting the pixel sets for analysis, CM-URSI does not need the SWIR acquisition in order to produce cloud mask.

<i>WorldView 2/3 ID</i>	<i>Acquisition date/time (UTC)</i>
104001000A704D00, 104A01000A704D00	2015-04-11 22:05:38
104001000C51A100, 104A01000C51A100	2015-05-26 22:16:39
104001000C463C00, 104A01000C463C00	2015-05-30 21:41:04
104001000DA92F00, 104A01000DA92F00	2015-06-20 22:13:15
104001000E7C1F00, 104A01000E7C1F00	2015-07-12 21:23:05
104001001C713100, 104A01001C713100	2016-05-11 23:08:43
104001006BCF9D00, 104A01006BCF9D00	2021-06-16 22:38:38
1040010077172D00, 104A010077172D00	2022-06-23 04:29:51
1040010078136700, 104A010078136700	2022-06-29 19:03:01
10400100776C7300, 104A0100776C7300	2022-06-29 22:12:48
104001007798DA00, 104A01007798DA00	2022-07-01 16:16:16
10400100771A0B00, 104A0100771A0B00	2022-07-14 13:07:19
104001009B264700, 104A01009B264700	2024-08-26 23:03:00
104001009CD02D00, 104A01009CD02D00	2024-09-04 23:53:48
104001009958D500, 104A01009958D500	2024-09-09 23:38:05
10300100FBD53400	2024-06-07 19:34:52
10300100FC0CA000	2024-06-07 19:33:31
10300100FC757300	2024-06-07 17:56:22
10300101021FE000	2024-08-07 19:19:13
10300101023F0100	2024-08-09 20:07:28
1040010096740900	2024-06-03 21:00:08
1040010097960600	2024-05-31 00:47:21
10400100986DE100	2024-06-05 18:16:53
10400100989D3B00	2024-08-08 18:25:23
10400100991D5A00	2024-08-09 18:41:14
1040010099D32B00	2024-08-08 21:37:40
104001009A456B00	2024-08-07 19:47:12
104001009B258000	2024-08-08 18:26:21
104001009BC51B00	2024-08-09 00:51:36

Table S1: Listing of WorldView scenes used in the study. WorldView-2 scene IDs begin with "103", and WorldView-3 scene IDs begin with "104". WorldView-3 SWIR scenes start with "104A".

Additional CM-URSI results

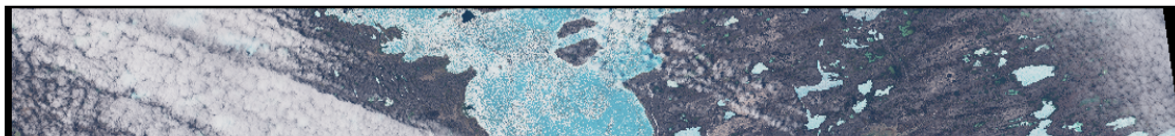
Here we present a couple of additional cases of CM-URSI cloud detection for complex scenes.

Our first scene in figure S3 shows a thin, broken cloud deck over a very varied land and water surface. This WorldView-3 scene was acquired in late June of 2022 and so there is a layer of water overlaying sea and lake ice in this scene, rather dramatically changing reflective properties of this ice. Note that it appears bright blue rather than the more common white. Nevertheless, CM-URSI successfully separates the cloud deck from this surface. There are some minor drop-outs where the cloud deck goes over a few tundra lakes, but overall the result is very good.

The second scene is another complex scene where on very close visual examination, possible at 3m resolution, there is a thin cloud deck present over mostly solid sea ice surface with some shadowing present on the surface as well. The sun angle is such that the ice, also likely in the process of melting as

the scene was acquired in a month of June, is very reflective, more reflective than the clouds even, which leads to a small amount of signal saturation in the WorldView-3 imagery.

a) True-color RGB image



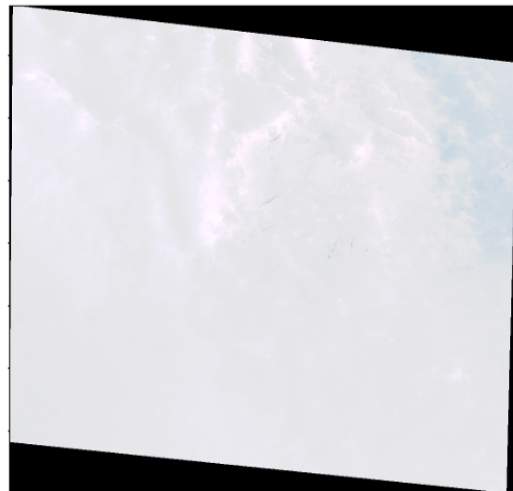
b) CM-URSI cloud mask



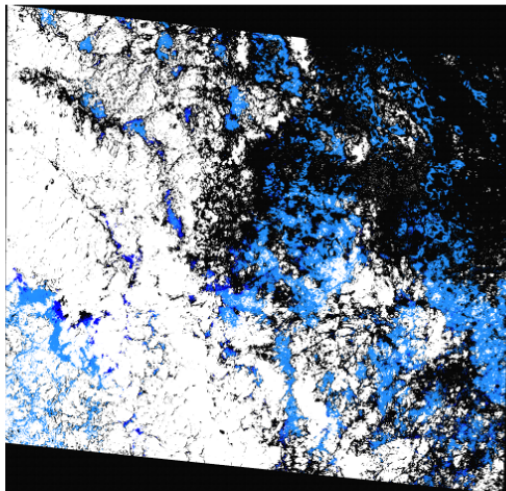
Conf. clear Conf. cloudy

Figure S3: WorldView-3 scene ID 1040010078136700 acquired on 06.29.2022 at 19:03:01 UTC, centered on 69.4°N, 102.0°W just east of Cambridge Bay, Nunavut. Panel a) shows the true-color image. Panel b) shows the CM-URSI cloud mask for this scene.

a) True-color RGB image



b) CM-URSI cloud mask



Conf. cloudy
Conf. clear

Figure S4: WorldView-3 scene ID 1040010096740900 acquired on 06.03.2024 at 21:00:08 UTC, centered on 83°N, 63°W in the Arctic Ocean north of Greenland. Panel a) shows the true-color image of this scene. Panel b) shows the CM-URSI cloud mask result for this scene.

CM-URSI processing path ID summary

Even though all these processing path IDs can be found in figures 6 and 7, we summarize the available values and how they are factored into cloudiness confidence values in table S2 for a quick reference.

<i>CM-URSI Processing Path ID</i>	<i>Cloud Mask Cloudiness Confidence Value</i>
-20	0 (confident clear)
-15	0 (confident clear)
-10	0 (confident clear)
-9.5	0 (confident clear)
-7	0 (confident clear)
-6.5	1 (most likely clear)
-6	0 (confident clear)
-5.5	2 (probably clear)
-5	0 (confident clear)
-4	0 (confident clear)
-3	2 (probably clear)
-2.5	3 (probably cloudy)
-2	3 (probably cloudy)
-1.5	4 (most likely cloudy)
-1	4 (most likely cloudy)
-0.5	4 (most likely cloudy)
0	1 (most likely clear)
2	5 (confident cloudy)
2.5	5 (confident cloudy)
3	5 (confident cloudy)
4	5 (confident cloudy)
9	5 (confident cloudy)
10	5 (confident cloudy)

Table S2: CM-URSI cloud mask confidence flag settings summary from Figures 6 and 7.