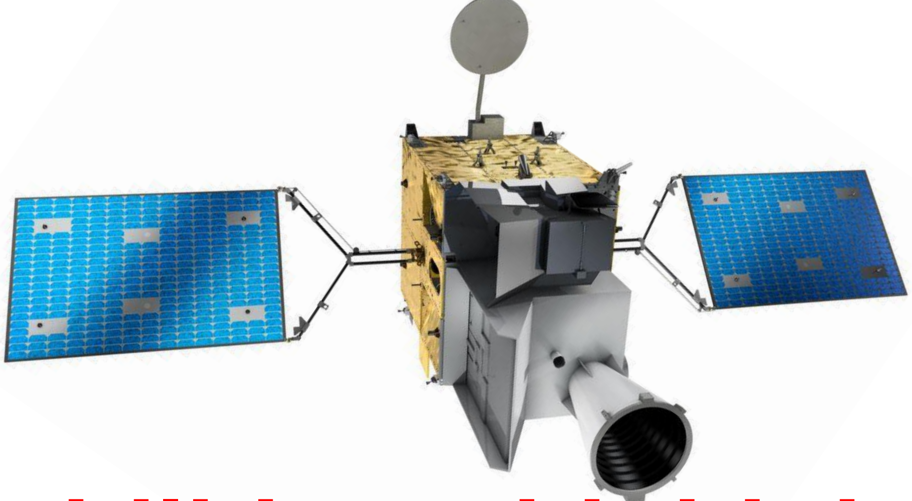


New capabilities with high resolution cloud micro-structure facilitated by MTG 2.3 um channel

Author:

Daniel Rosenfeld
The Hebrew University of Jerusalem (HUJ)
daniel.rosenfeld@huji.ac.il

9 November 2016, V1.0

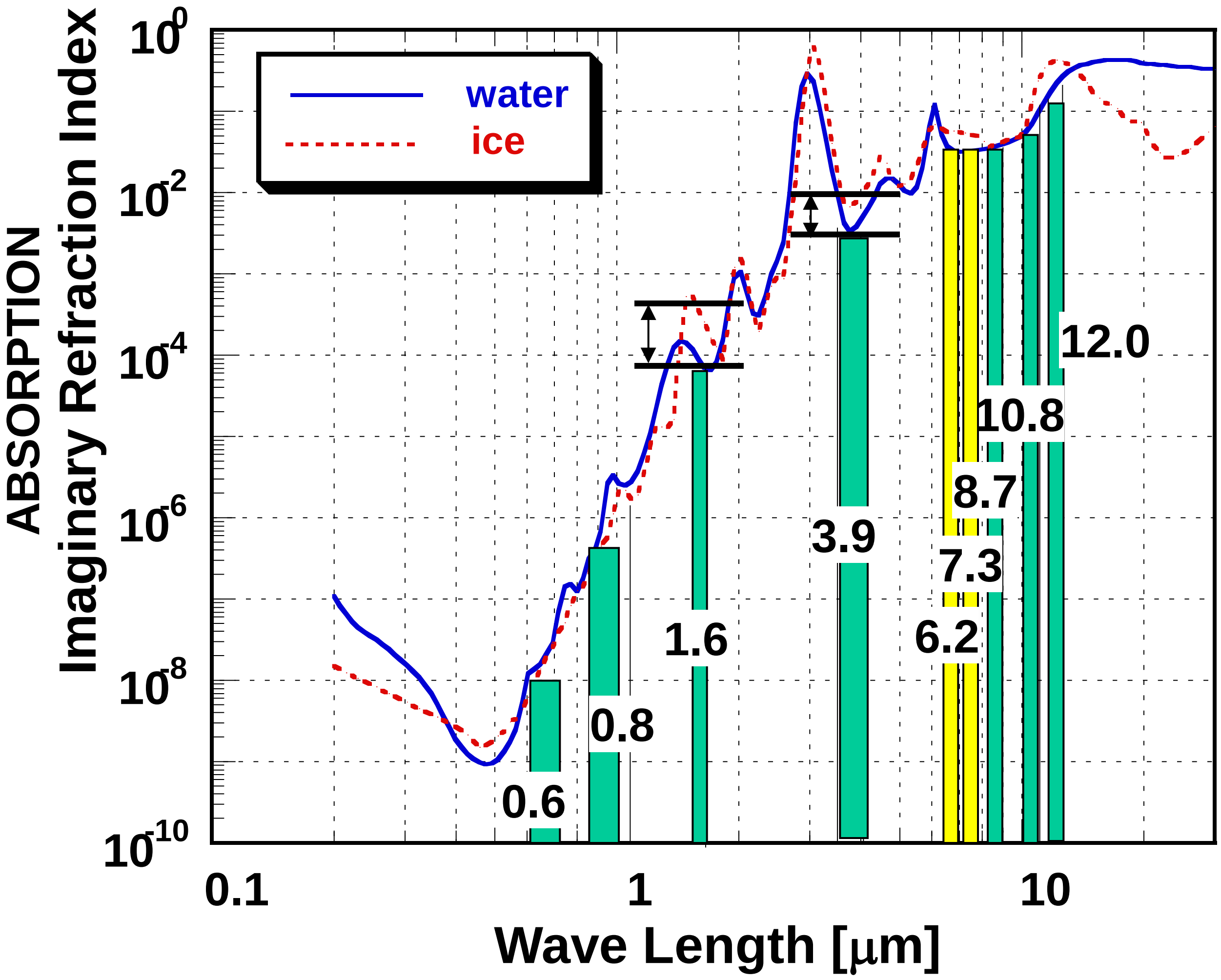
Prof. Daniel Rosenfeld

The Hebrew University of Jerusalem, Israel

Daniel.rosenfeld@Huji.ac.il

Areas of specialty:
Cloud-aerosol interactions, precipitation and climate.
Severe convective storms.
Remote sensing of clouds.

How can we detect from space the phase and size of microscopic cloud particles?

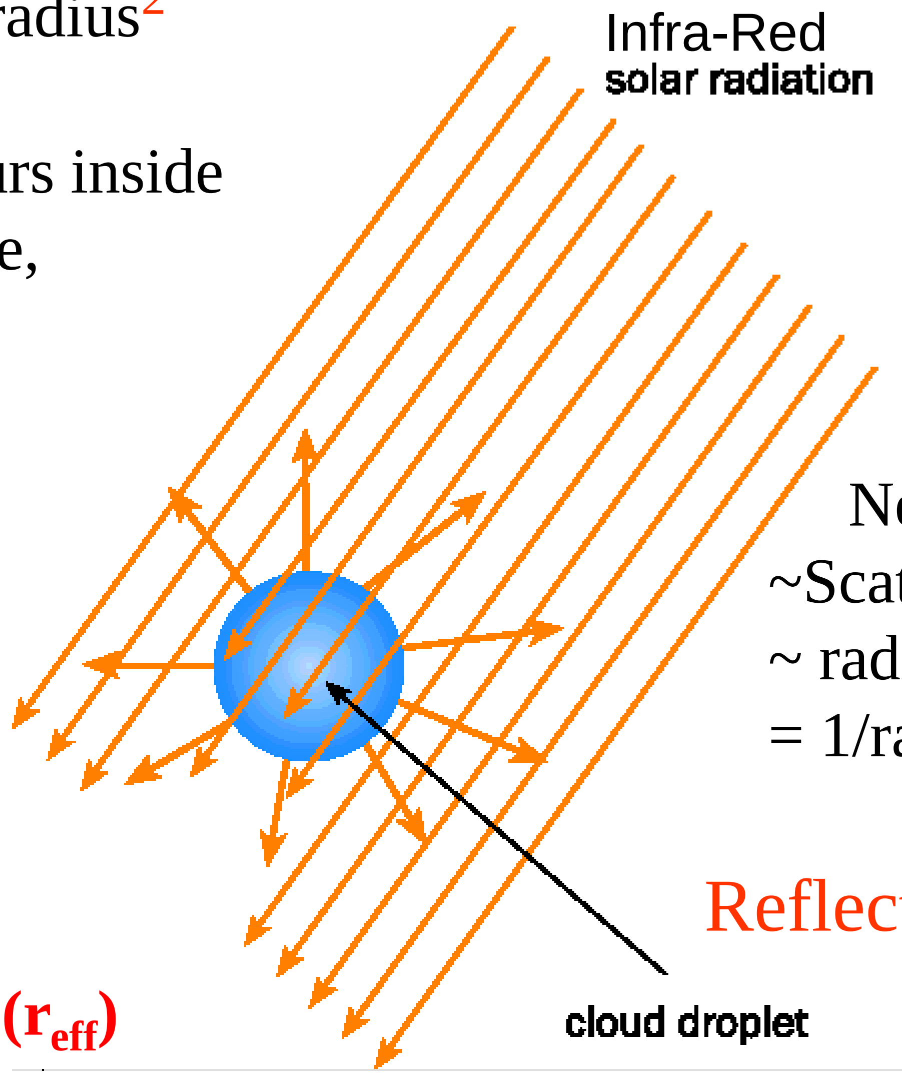


Slide 3

Channel 4, 3.9 μm, absorbs even more solar radiation than Channel 3, 1.6 μm. Ice absorbs more strongly than water at 3.9 μm.

Scattering occurs on the drop surface, ~ radius^2

Absorption occurs inside
The drop volume,
~ radius^3



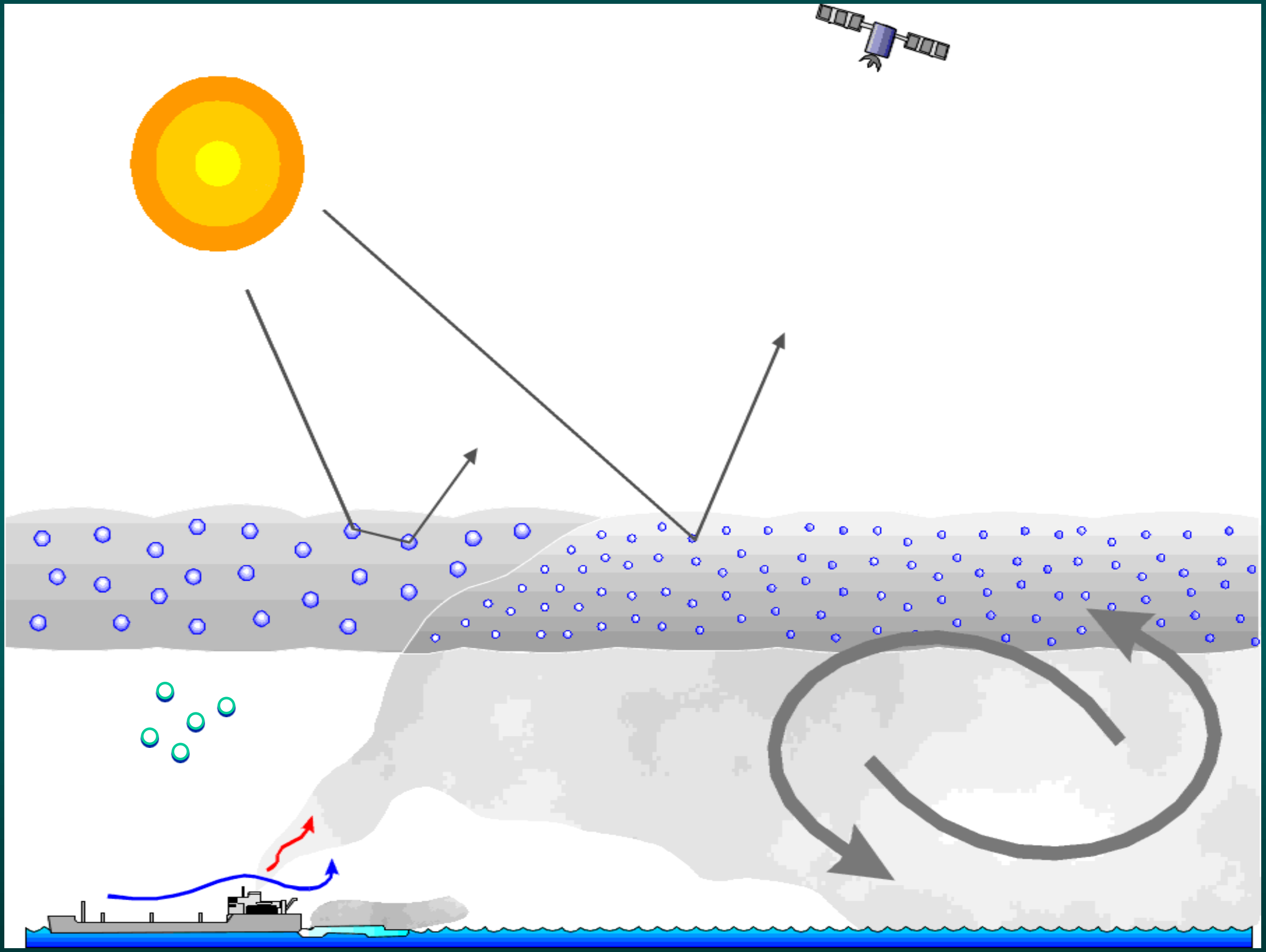
Net reflectance
~Scattering / Absorption
~ radius^2 / radius^3
= 1/radius

Reflectance ~ Radius^{-1}

Definition of
Effective Radius **(r_{eff})**
of cloud droplets:
Sum of volumes / sum of surface areas
of the droplets in the measured cloud volume

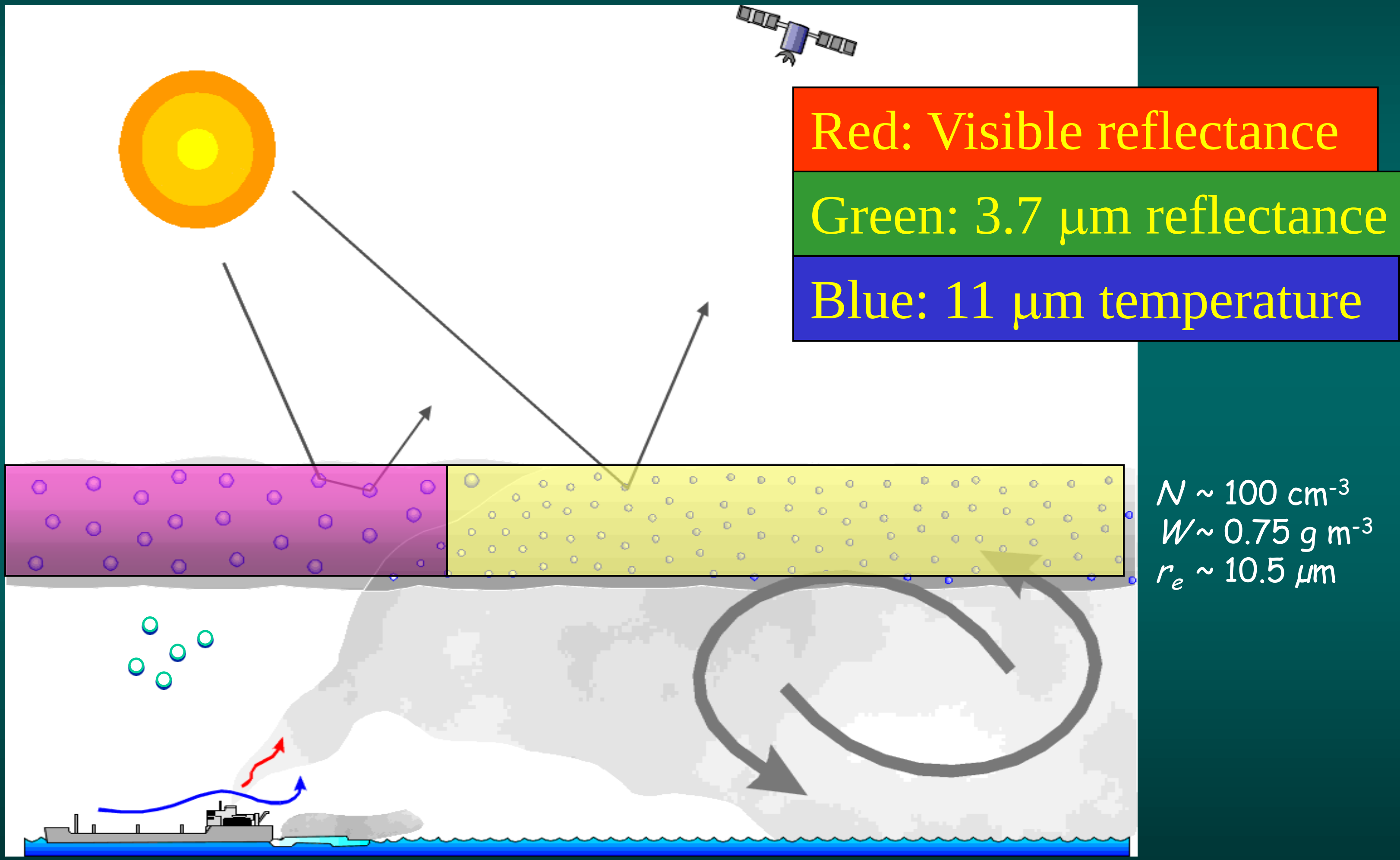
Ship Track Formation

N ~ 40 cm^{-3}
W ~ 0.30 g m^{-3}
r_e ~ 11.2 μm



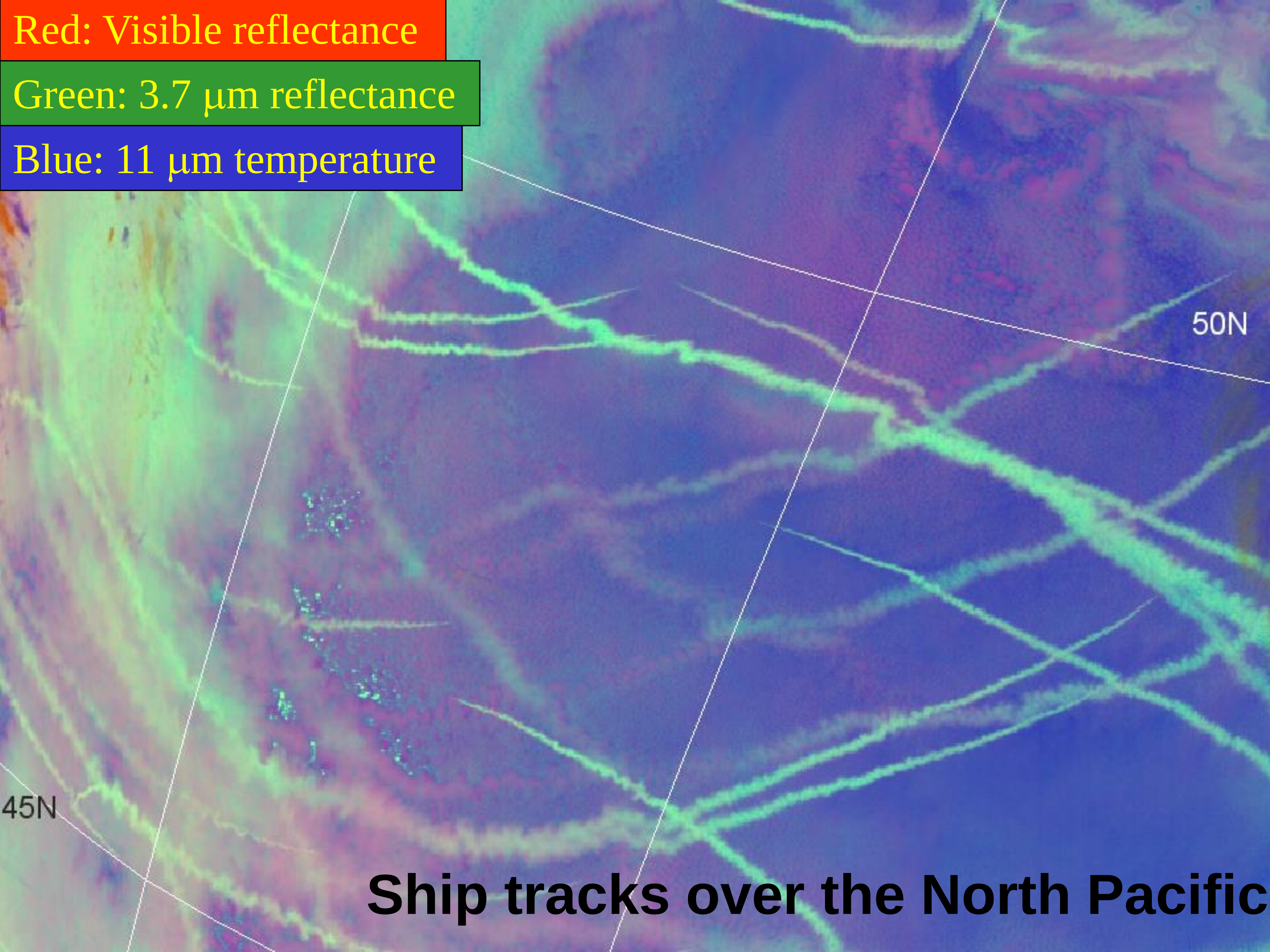
N ~ 100 cm^{-3}
W ~ 0.75 g m^{-3}
r_e ~ 10.5 μm

Ship Track Formation

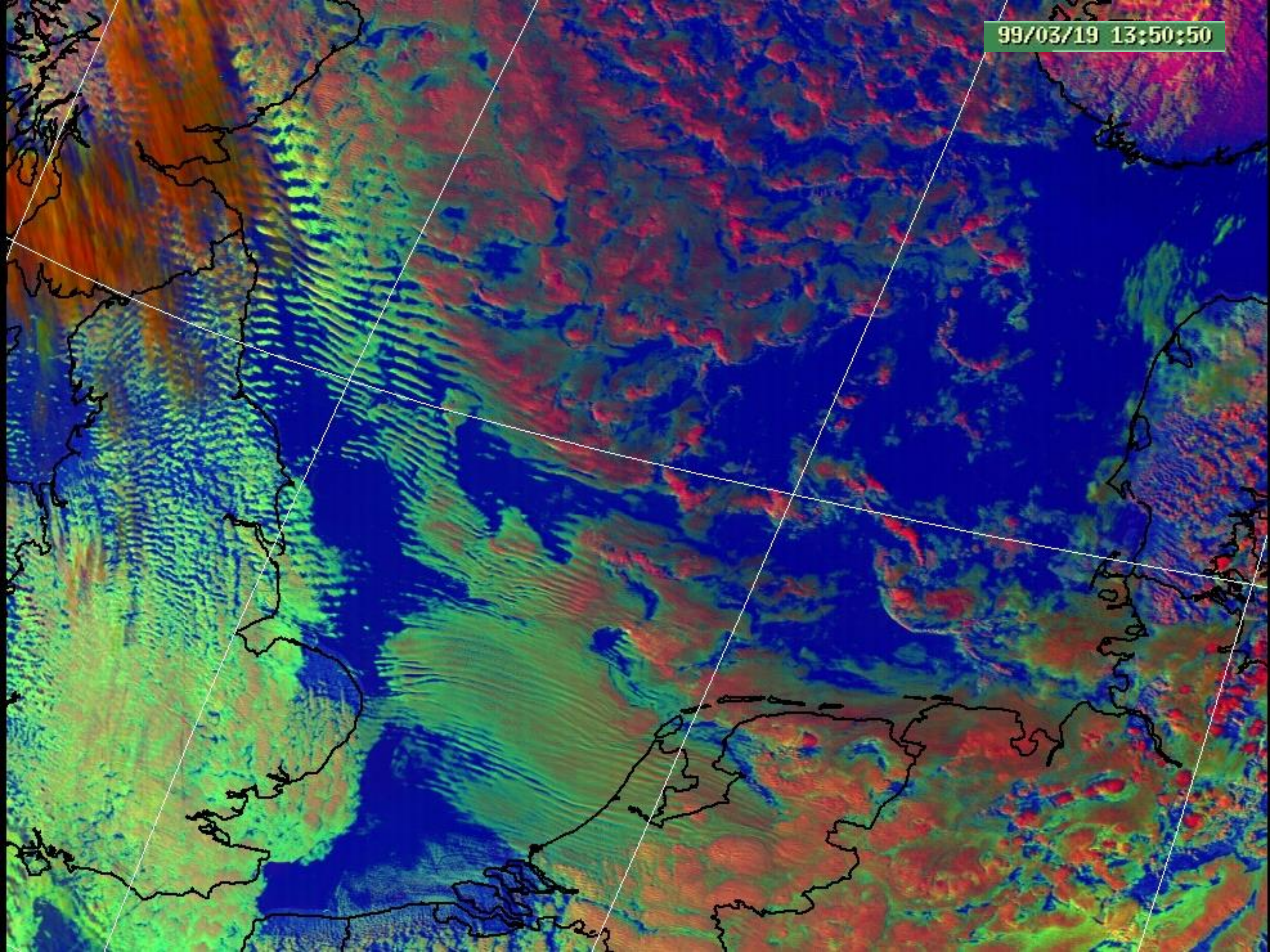


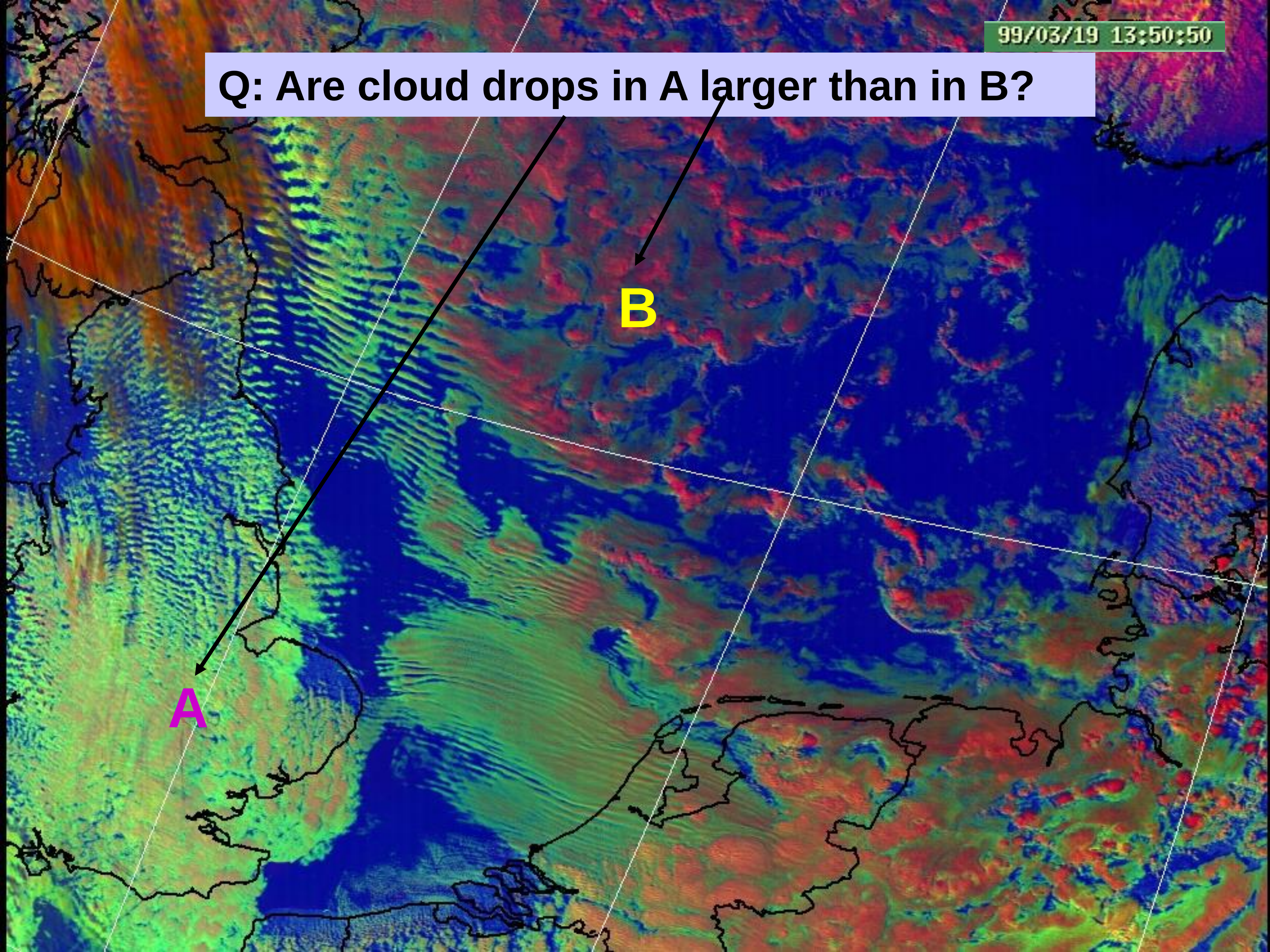
N ~ 40 cm^{-3}
W ~ 0.30 g m^{-3}
r_e ~ 11.2 µm

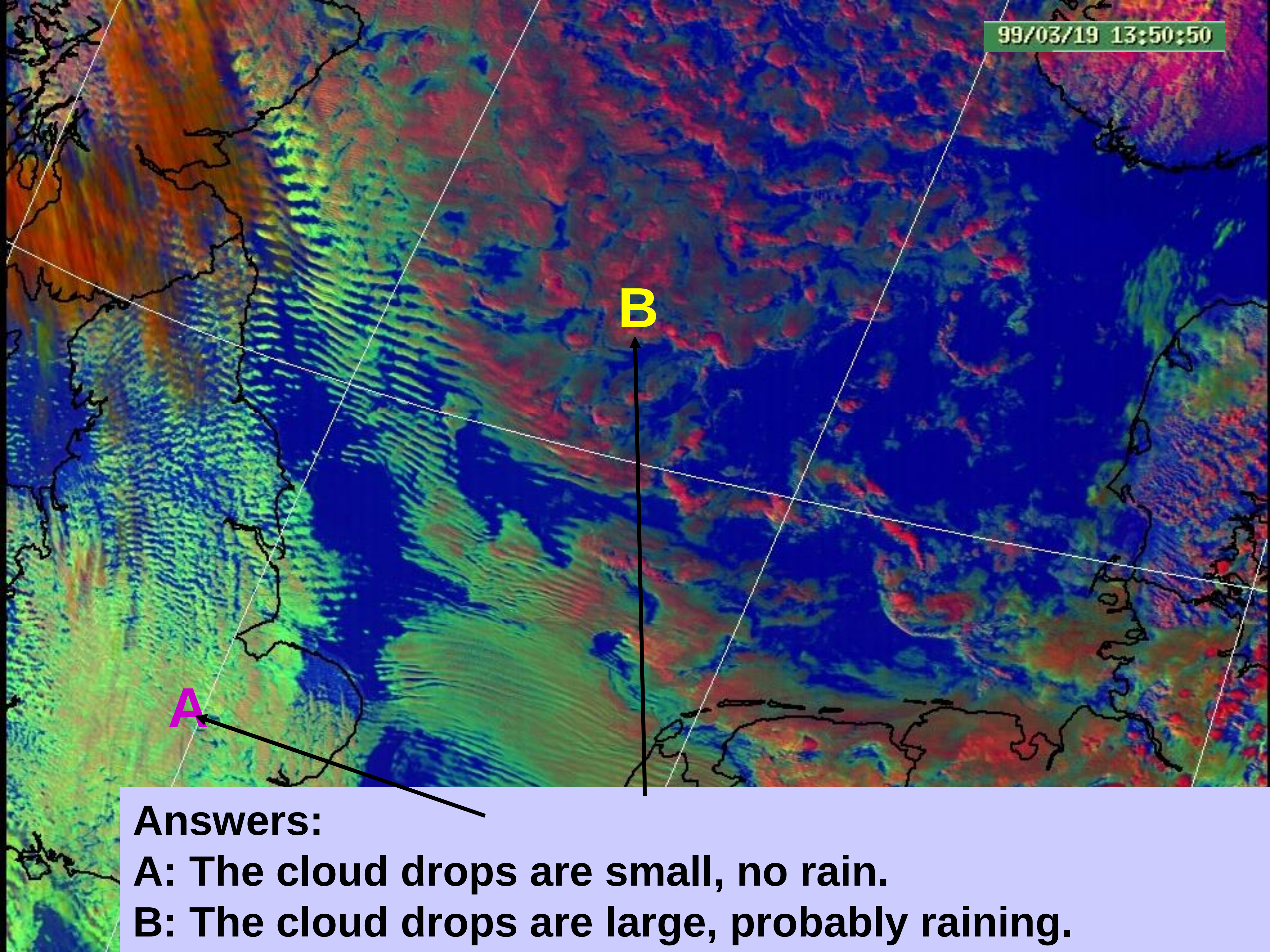
N ~ 100 cm^{-3}
W ~ 0.75 g m^{-3}
r_e ~ 10.5 µm



Ship tracks over the North Pacific


99/03/19 13:50:50

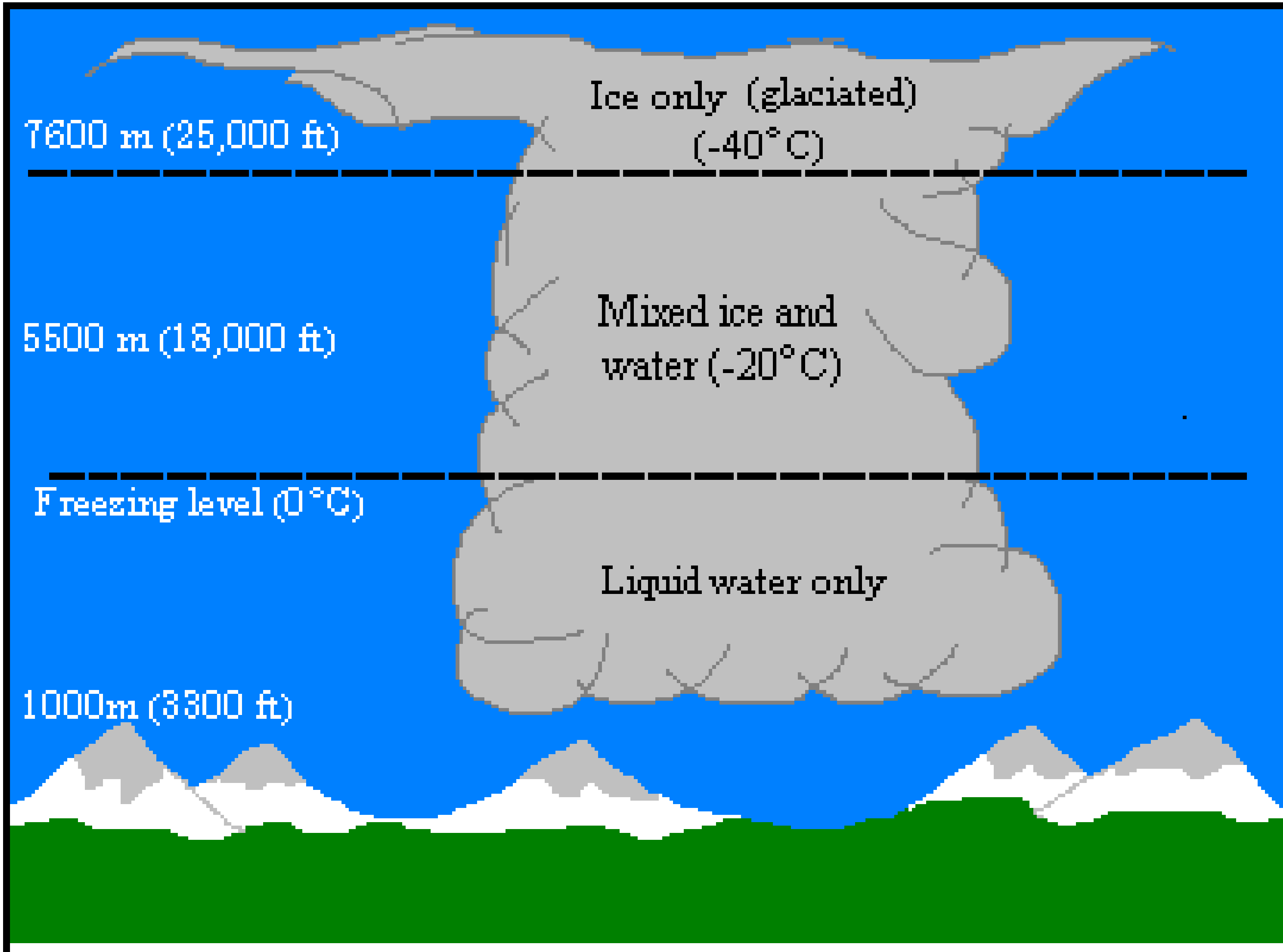

99/03/19 13:50:50
Q: Are cloud drops in A larger than in B?
B
A



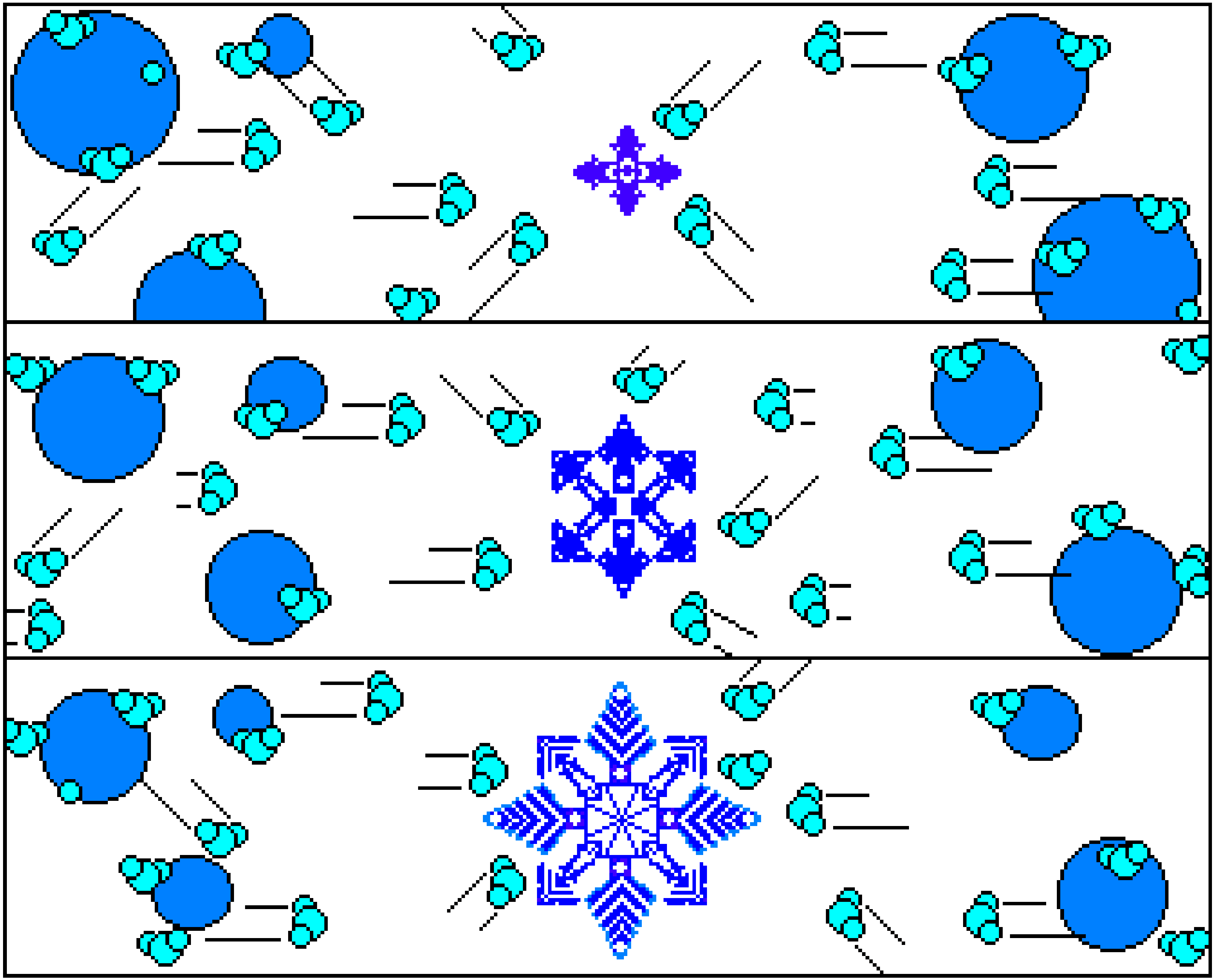
Answers:

A: The cloud drops are small, no rain.

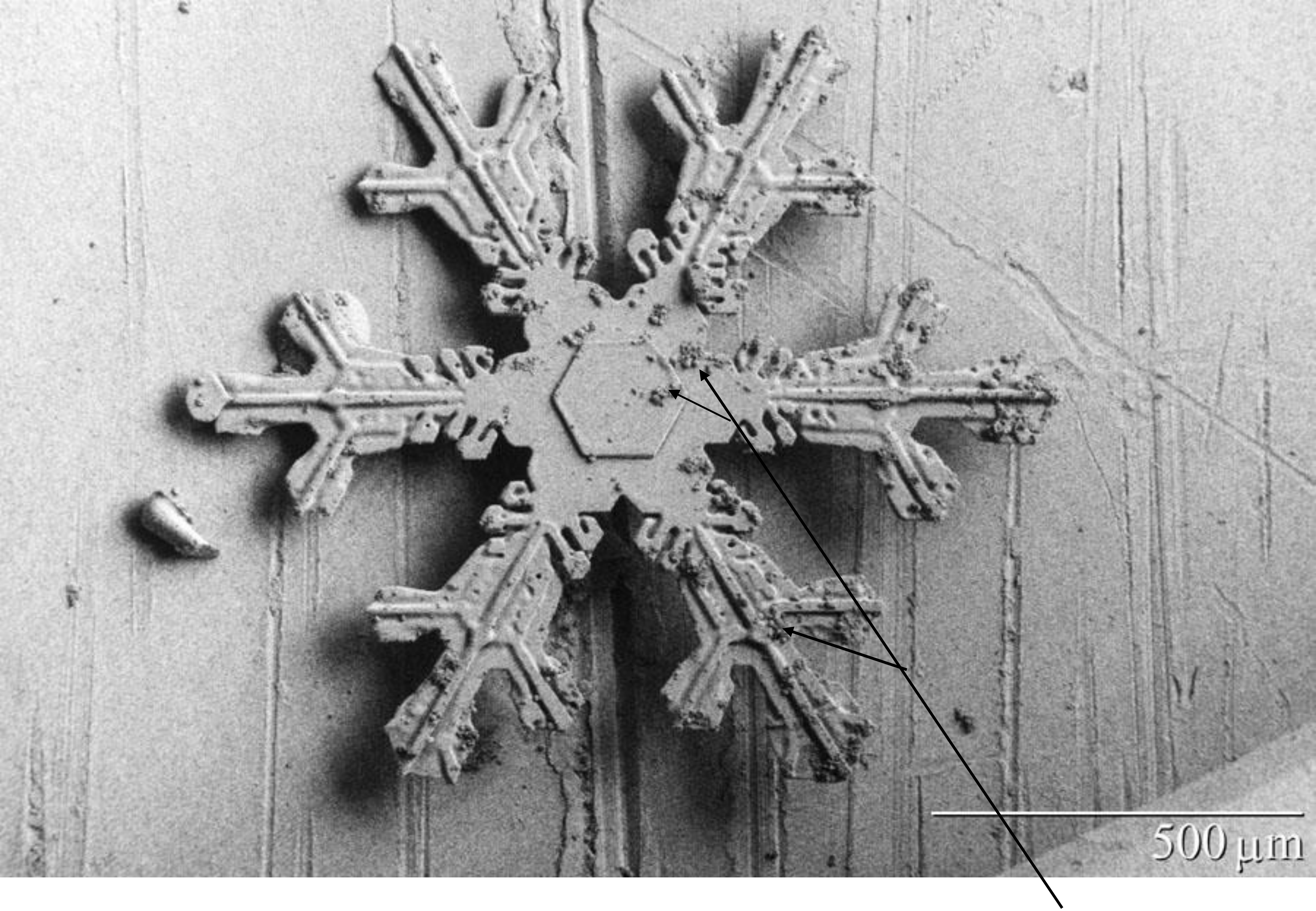
B: The cloud drops are large, probably raining.



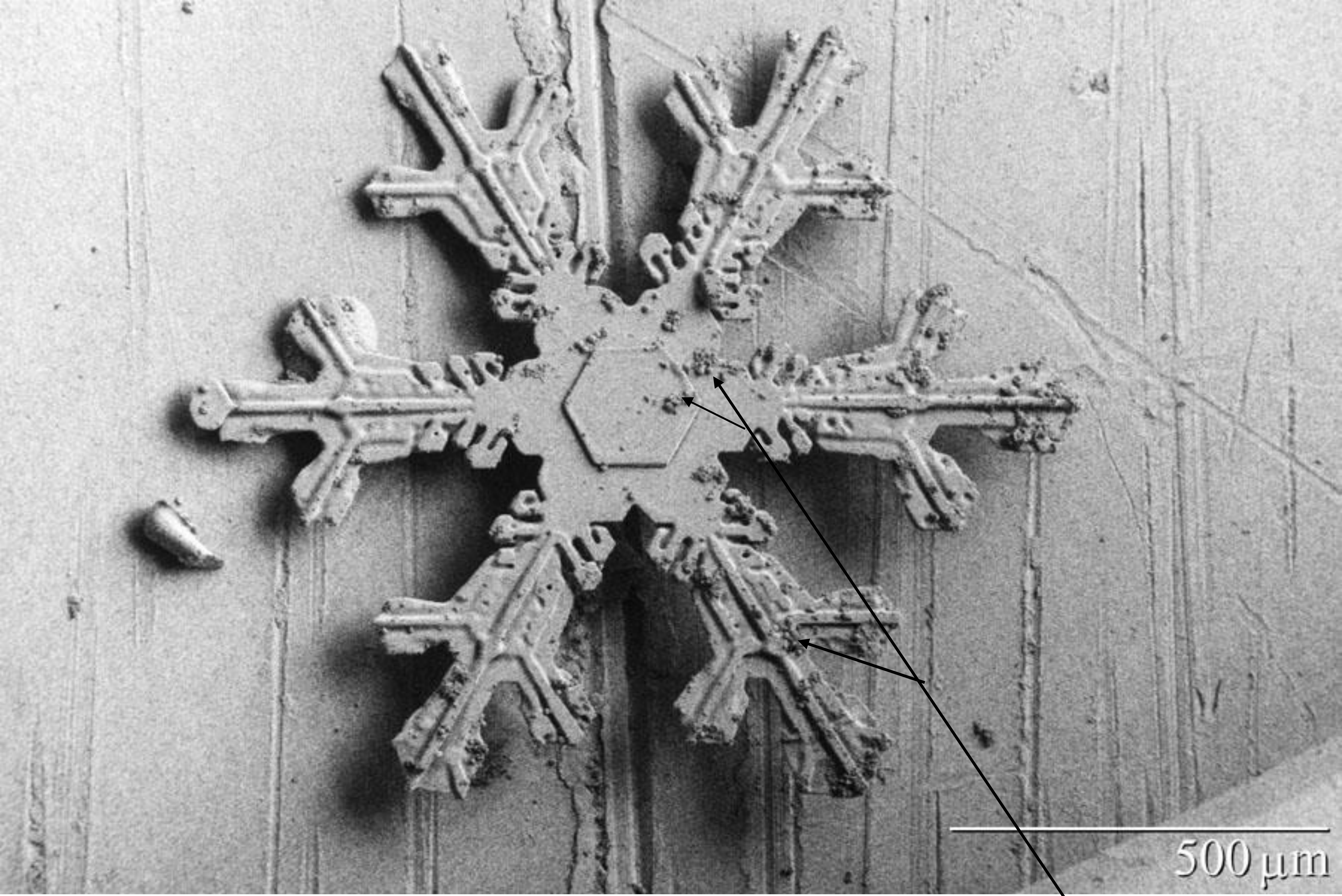
How can we distinguish between water and ice cloud?



Bergeron process



Large ice crystal collects small supercooled cloud drops

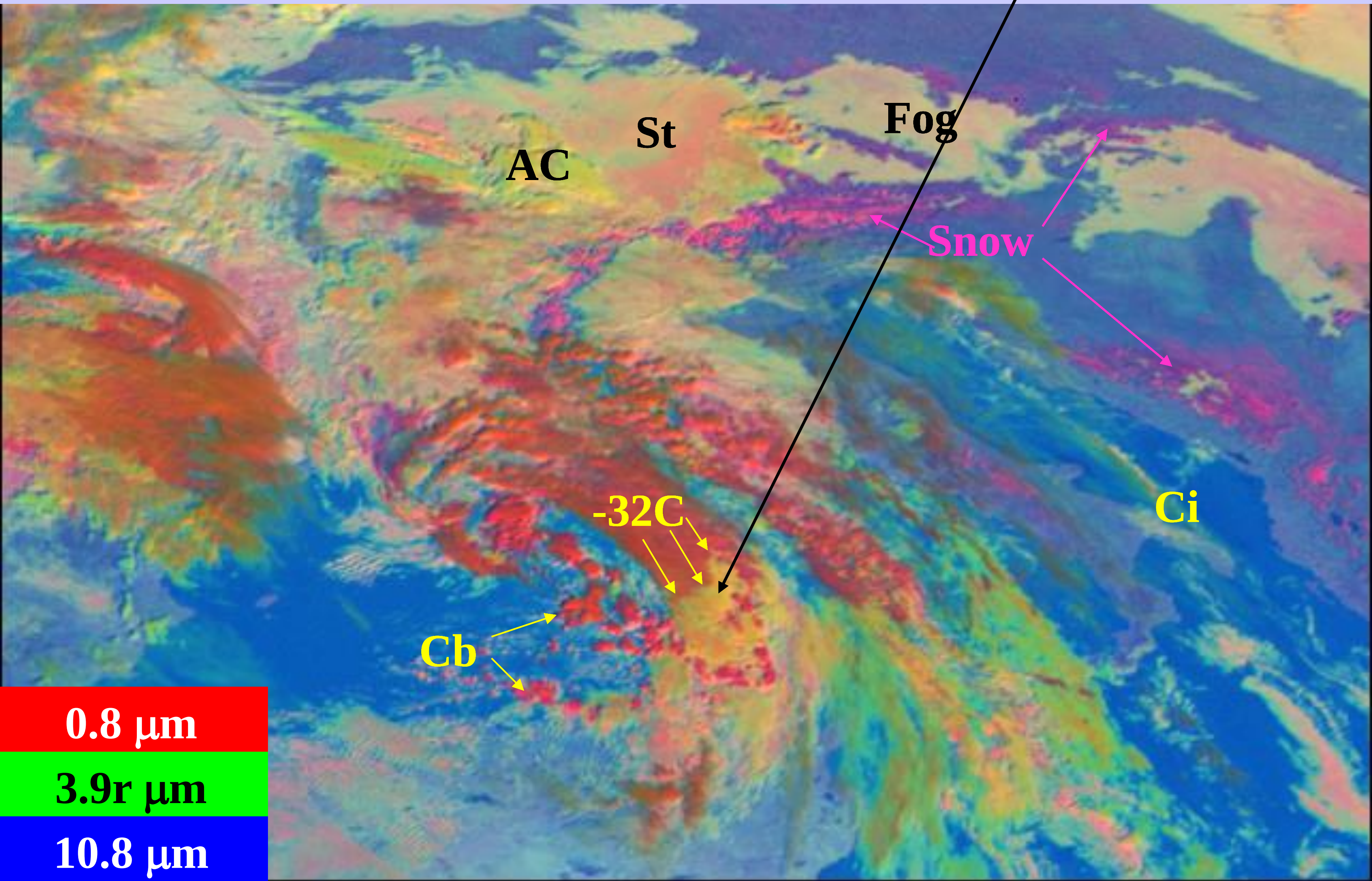


Problem: Ice cloud looks like water cloud with large drops!

2003/12/19 10:27 CH02 0.8 CH04 A3.9 CH09 10.8

Cold cloud with small supercooled drops:

Low T +Visibly Bright +Small Drops =



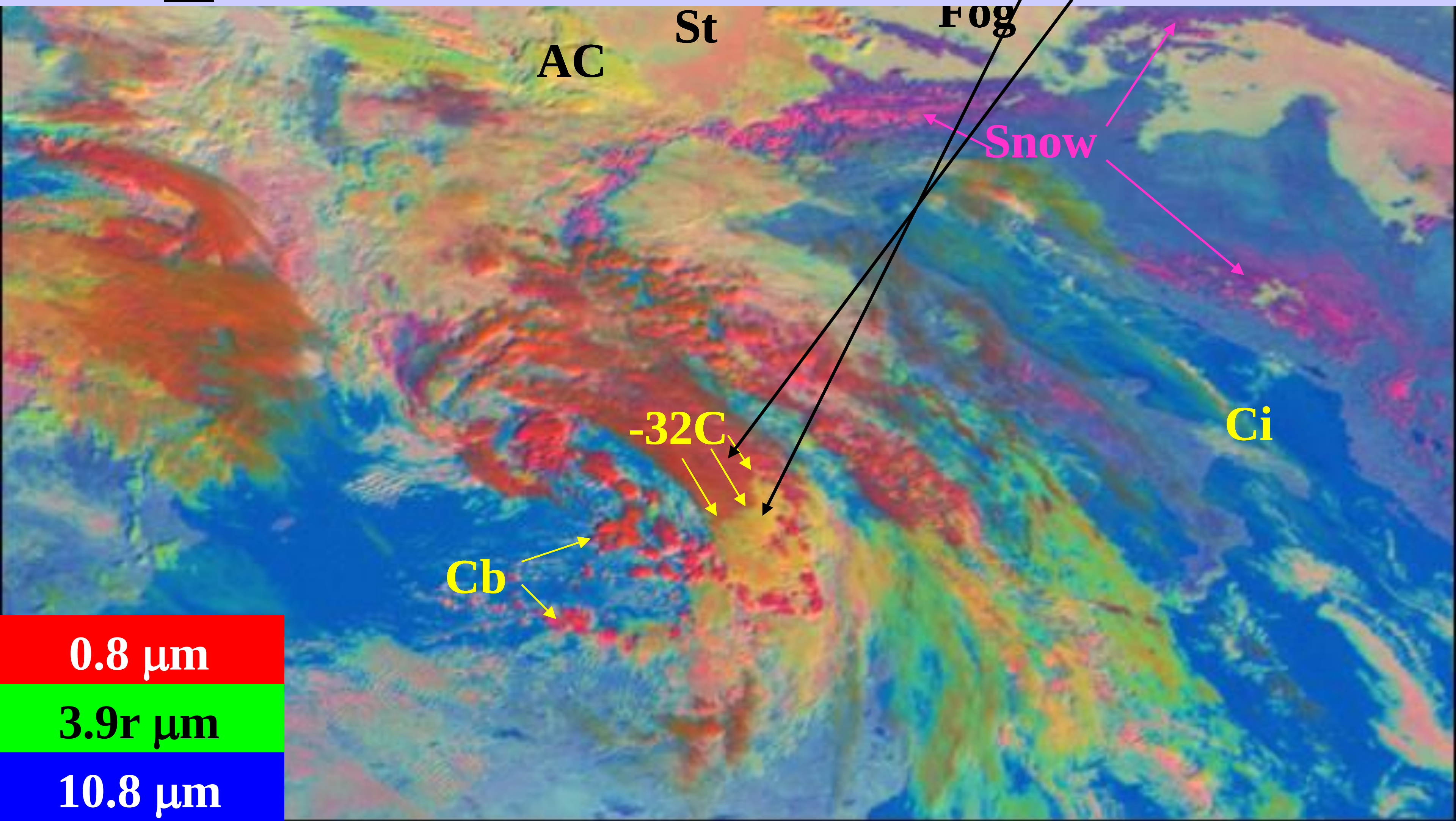
2003/12/19 10:27 CH02 0.8 CH04 A3.9 CH09 10.8

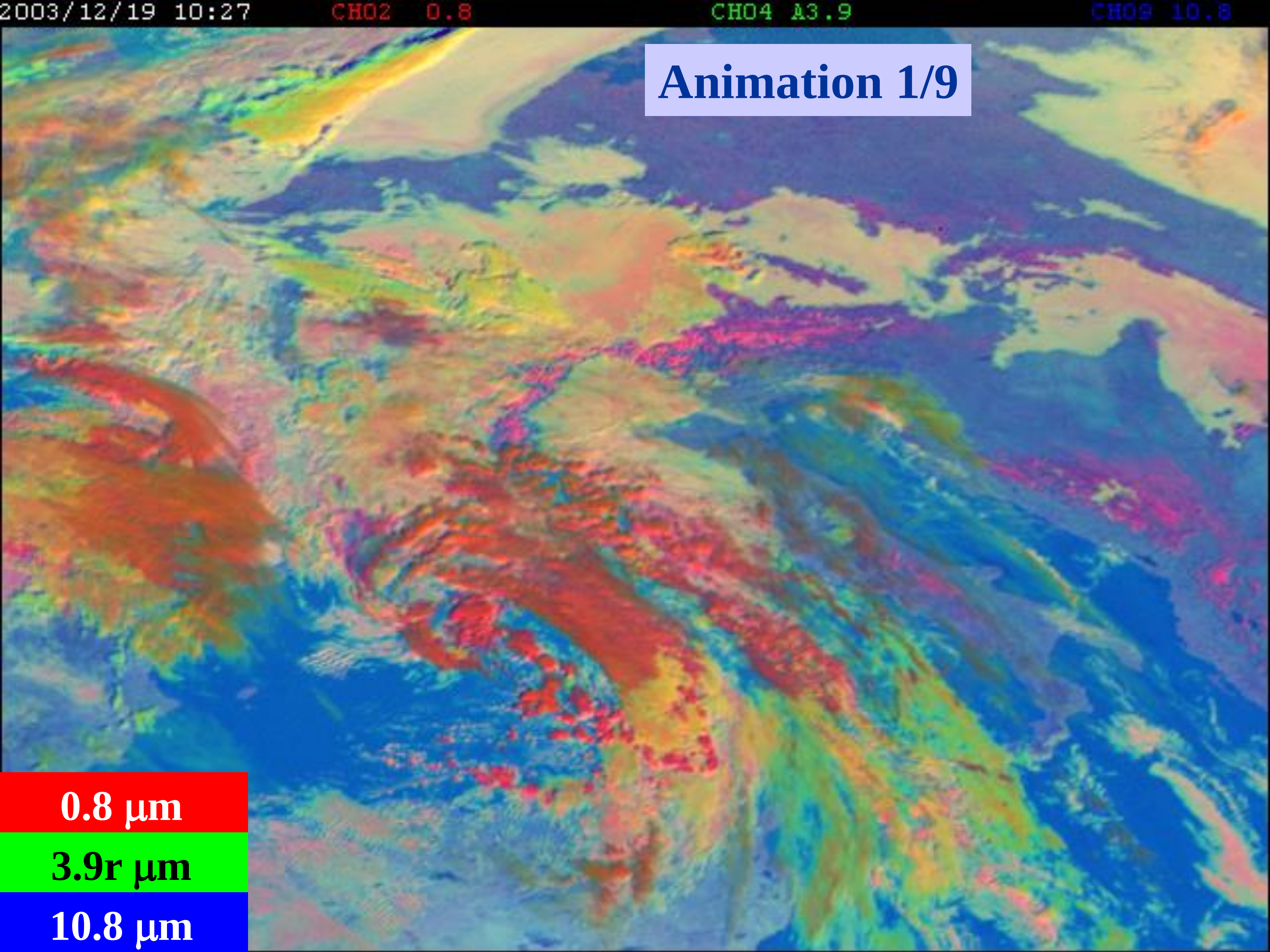
Cold cloud with small supercooled drops:

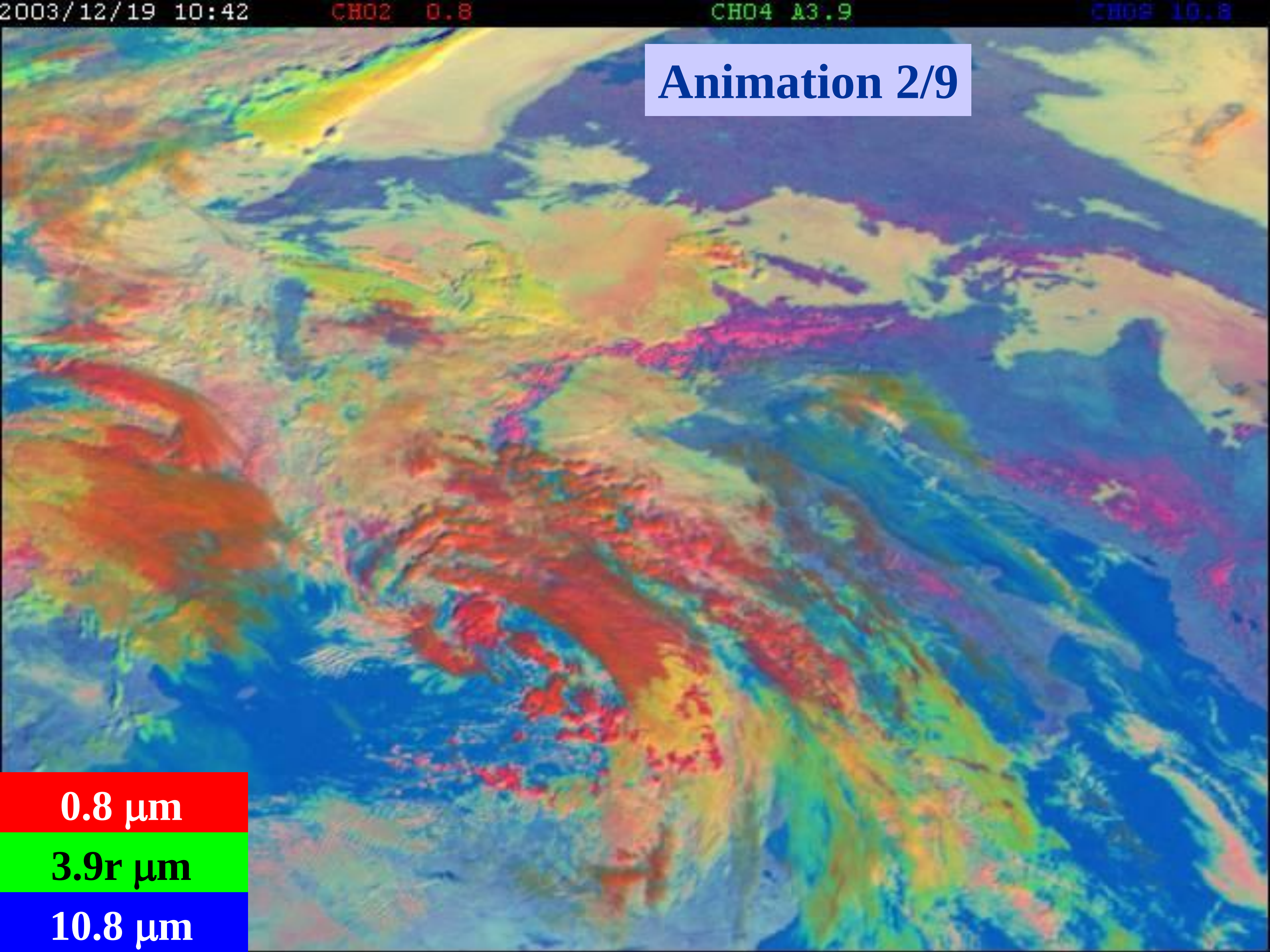
Low T +Visibly Bright +Small Drops =

Cold cloud with large ice crystals:

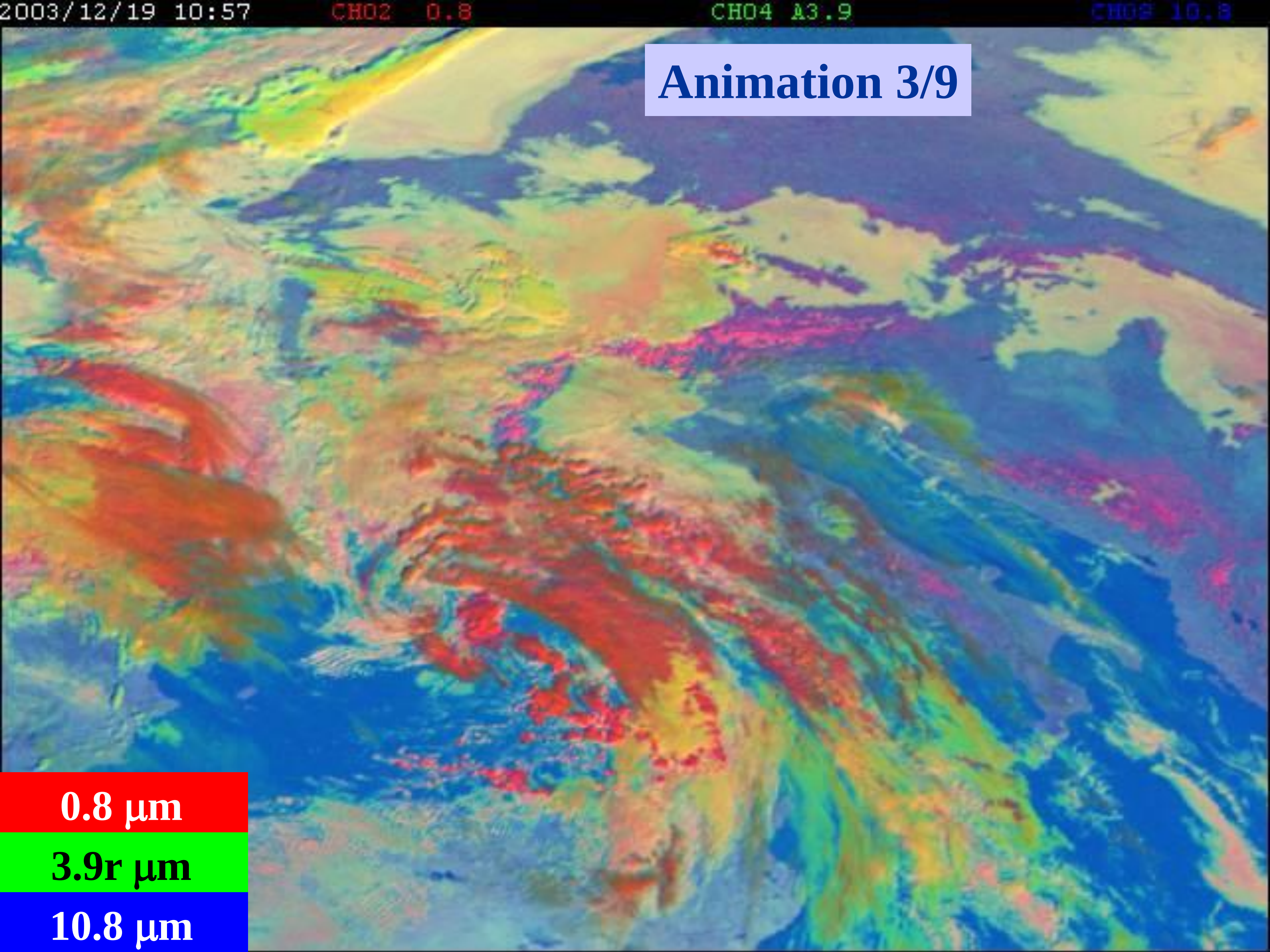
Low T +Visibly Bright +Large Ice =



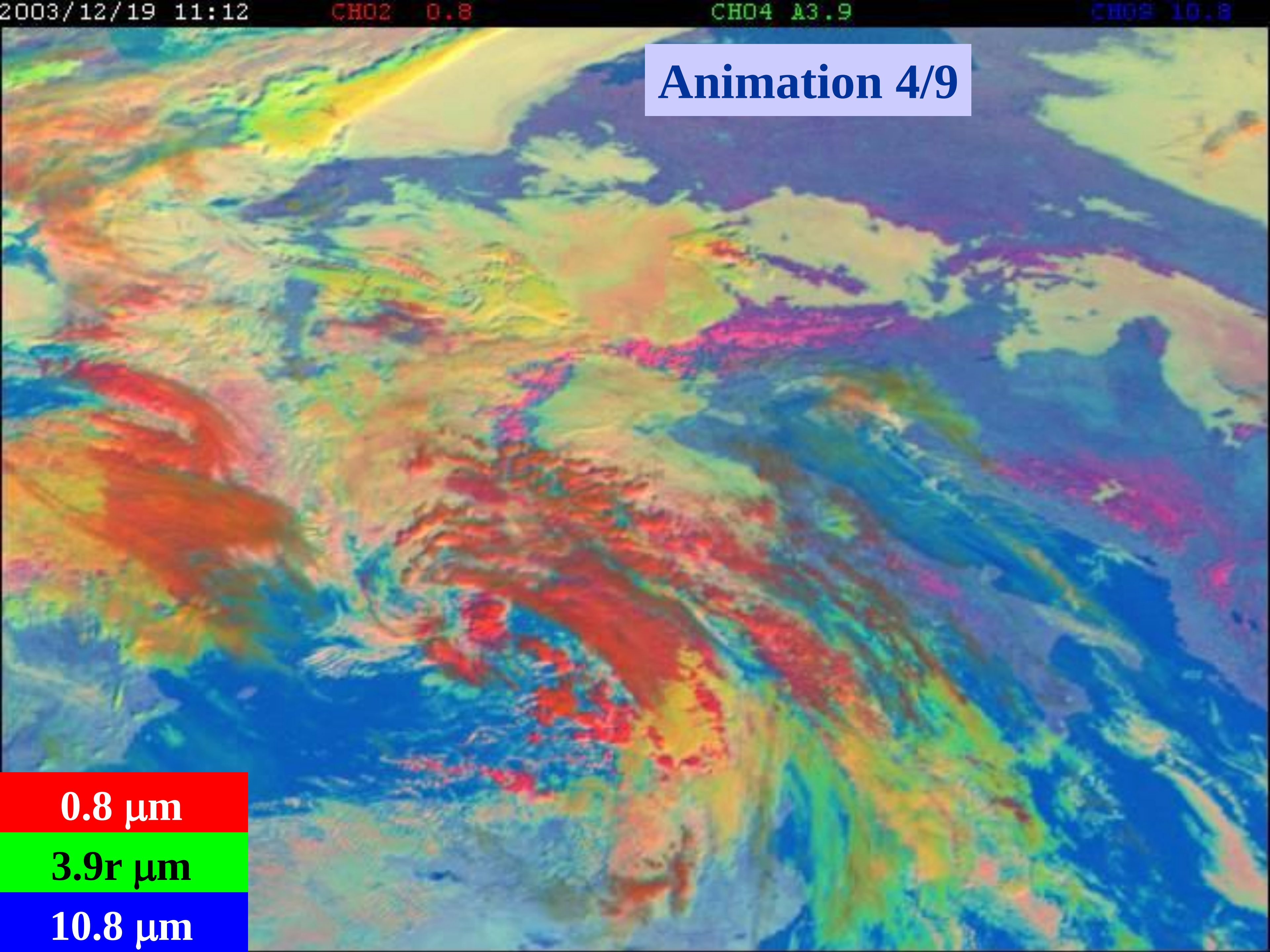

2003/12/19 10:27
CH02 0.8
CH04 A3.9
CH09 10.8
Animation 1/9
0.8 µm
3.9r µm
10.8 µm


2003/12/19 10:42
CH02 0.8
CH04 A3.9
Animation 2/9
0.8 µm
3.9r µm
10.8 µm

Animation 3/9



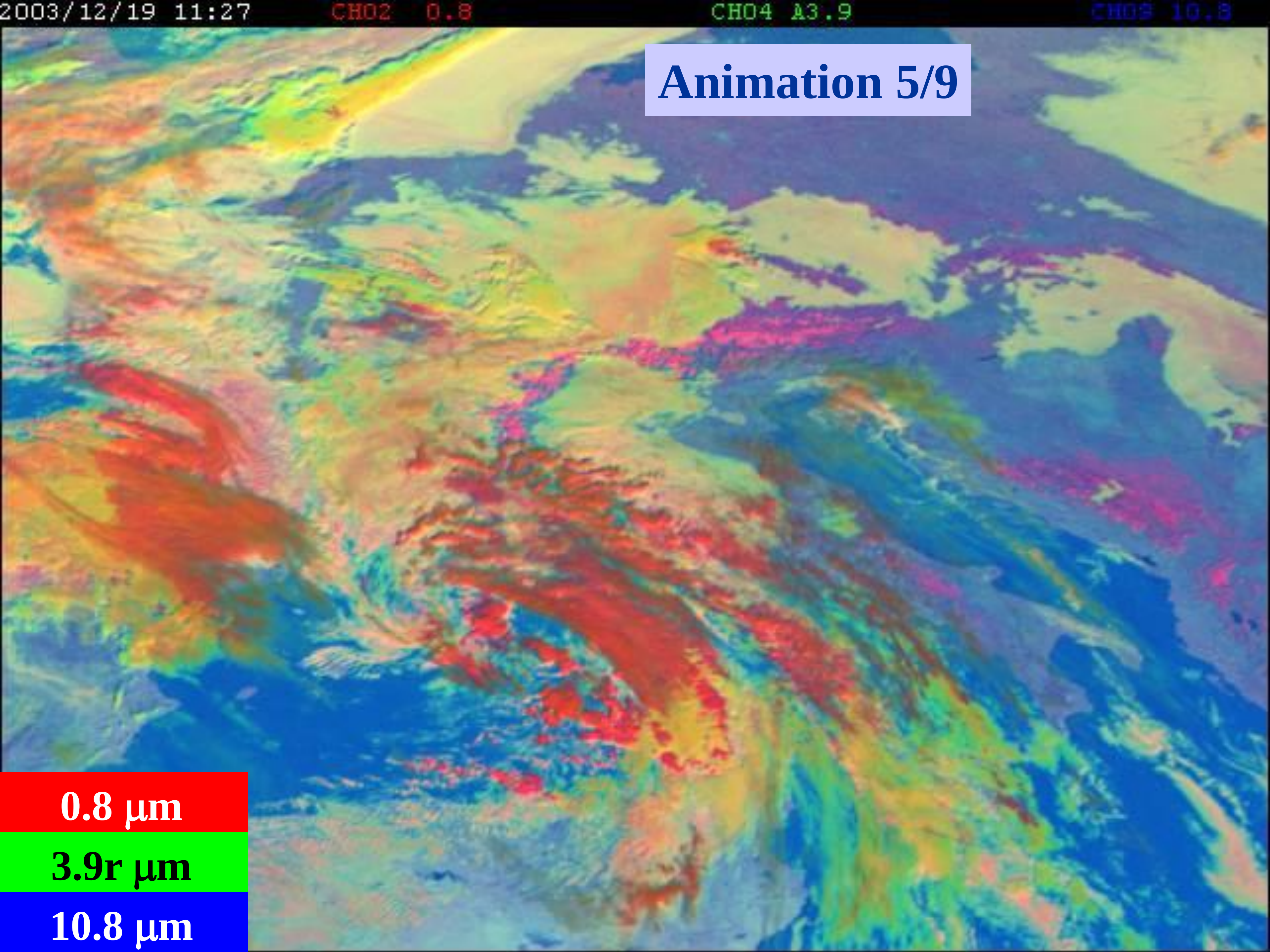
Animation 4/9

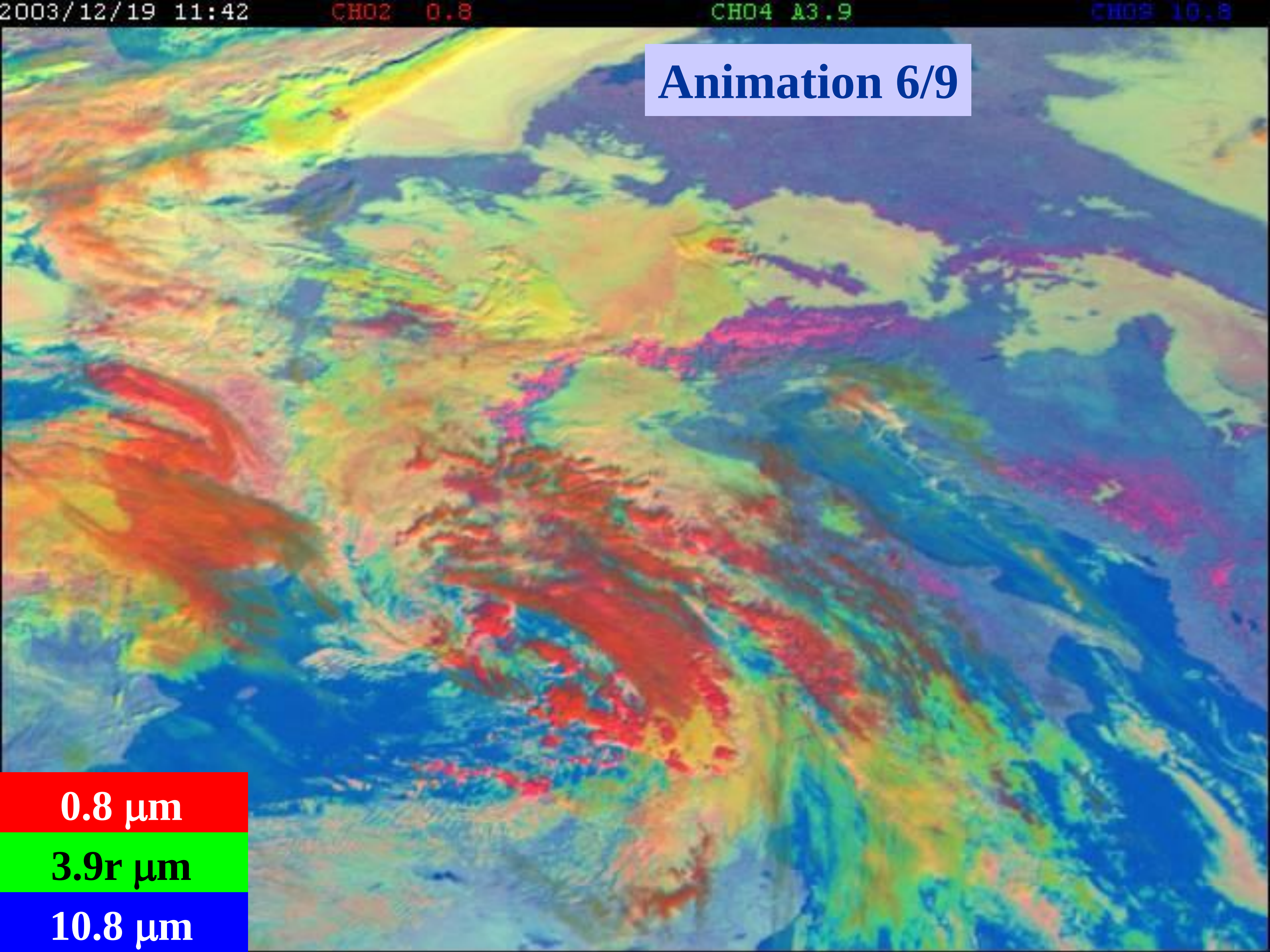


0.8 µm

3.9r µm

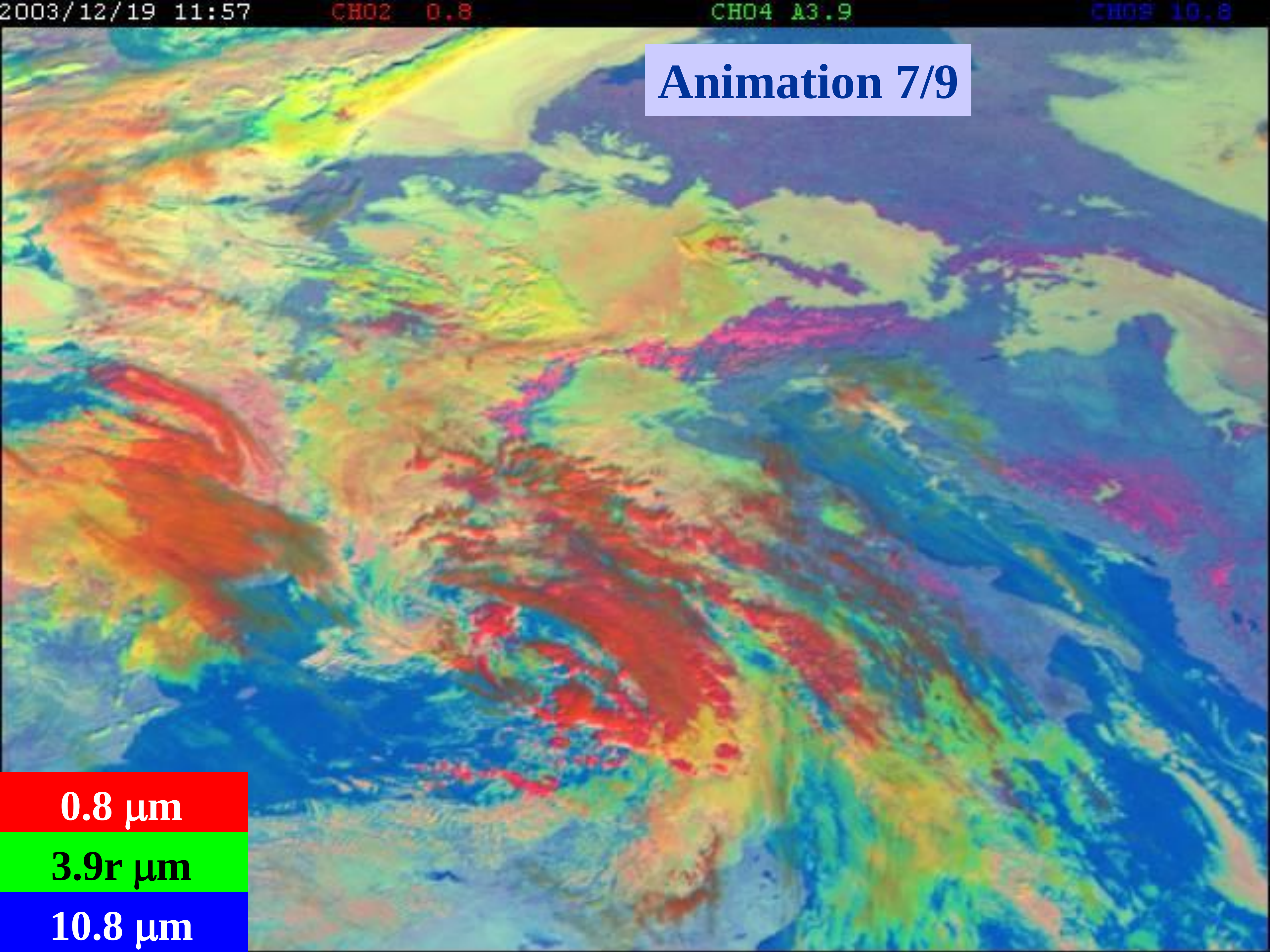
10.8 µm


2003/12/19 11:27
CH02 0.8
CH04 A3.9
CH09 10.8
Animation 5/9
0.8 µm
3.9r µm
10.8 µm

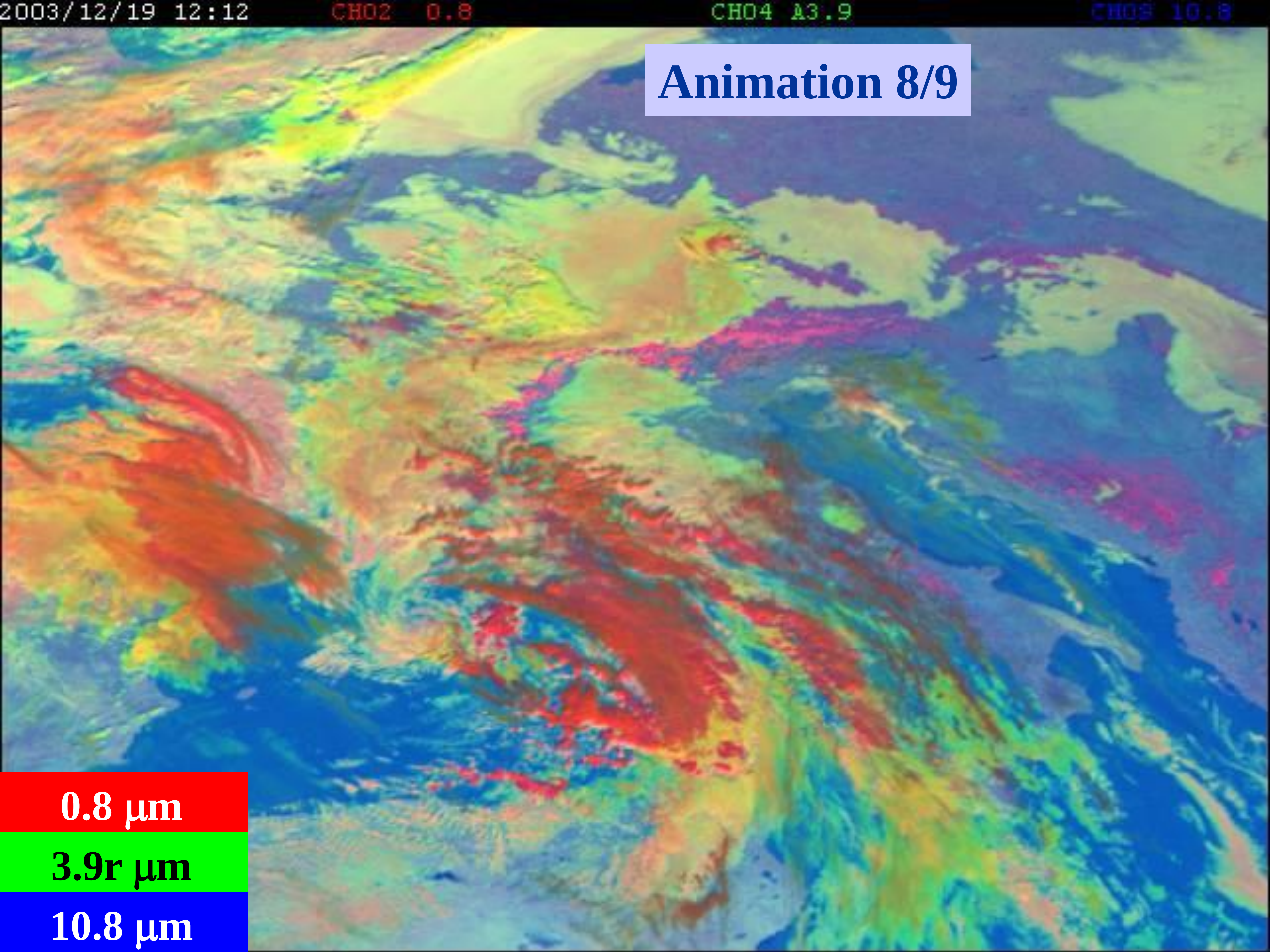


2003/12/19 11:42
CH02 0.8
CH04 A3.9
Animation 6/9
0.8 µm
3.9r µm
10.8 µm

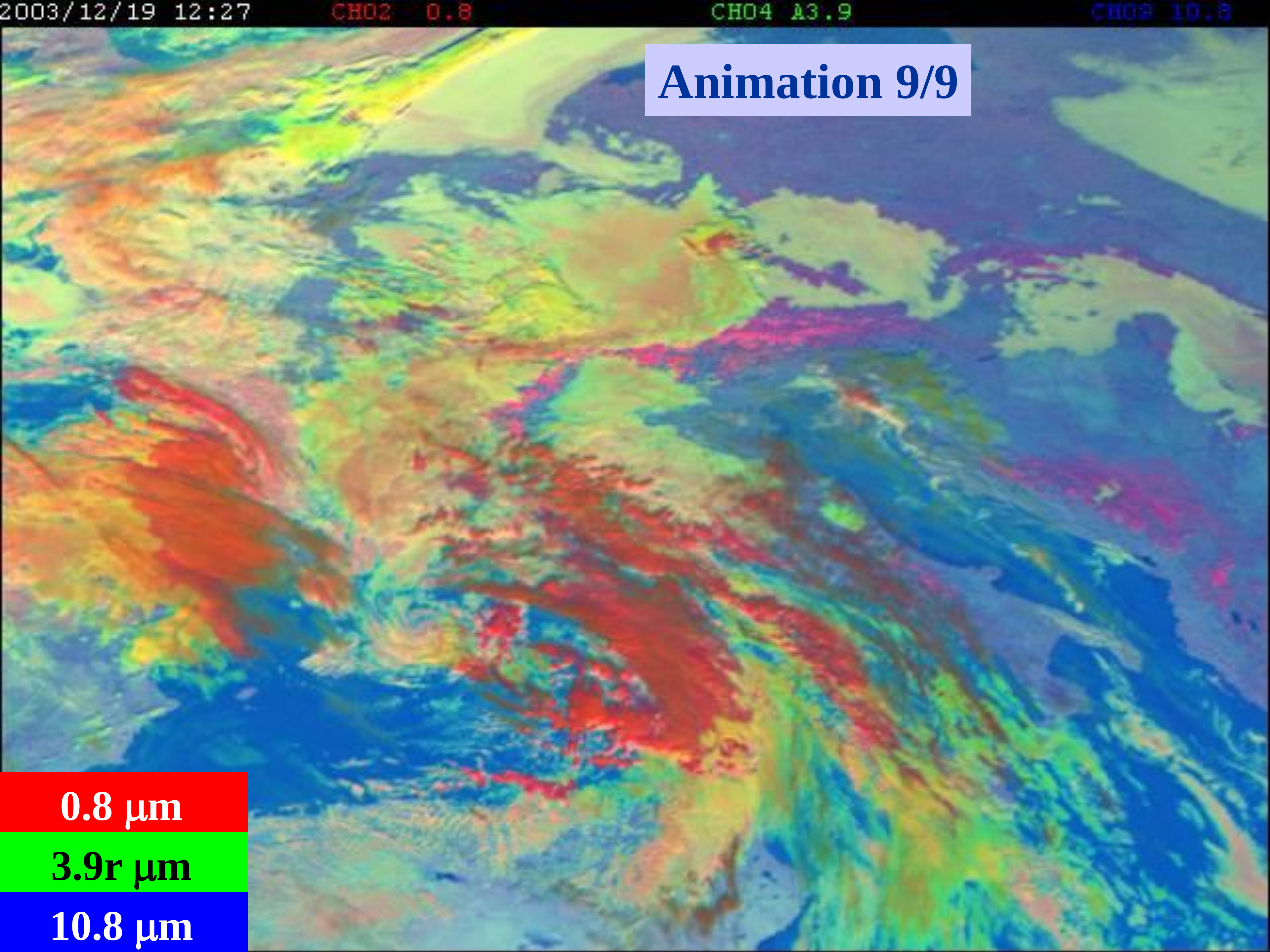
Animation 7/9



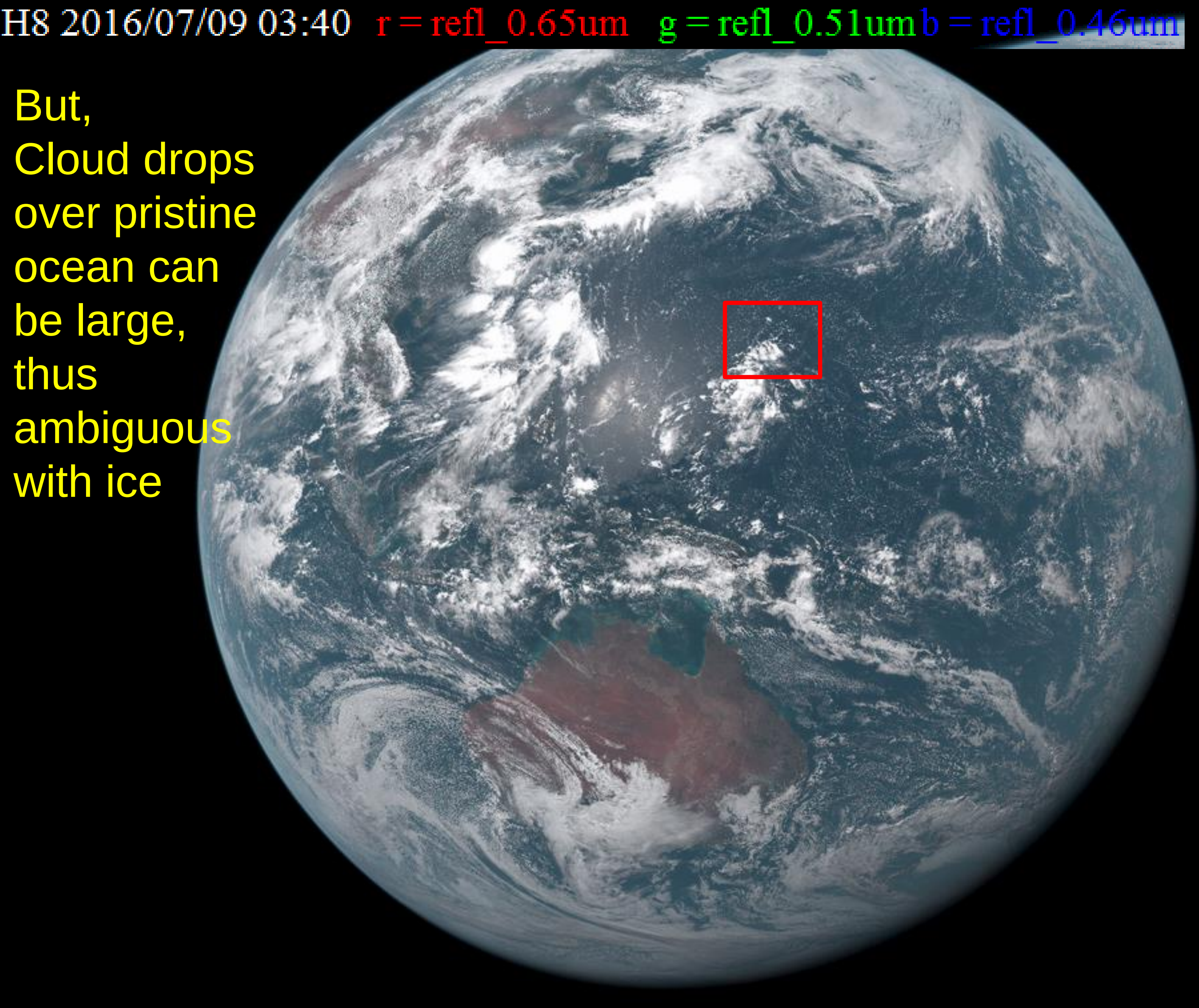
0.8 µm
3.9r µm
10.8 µm

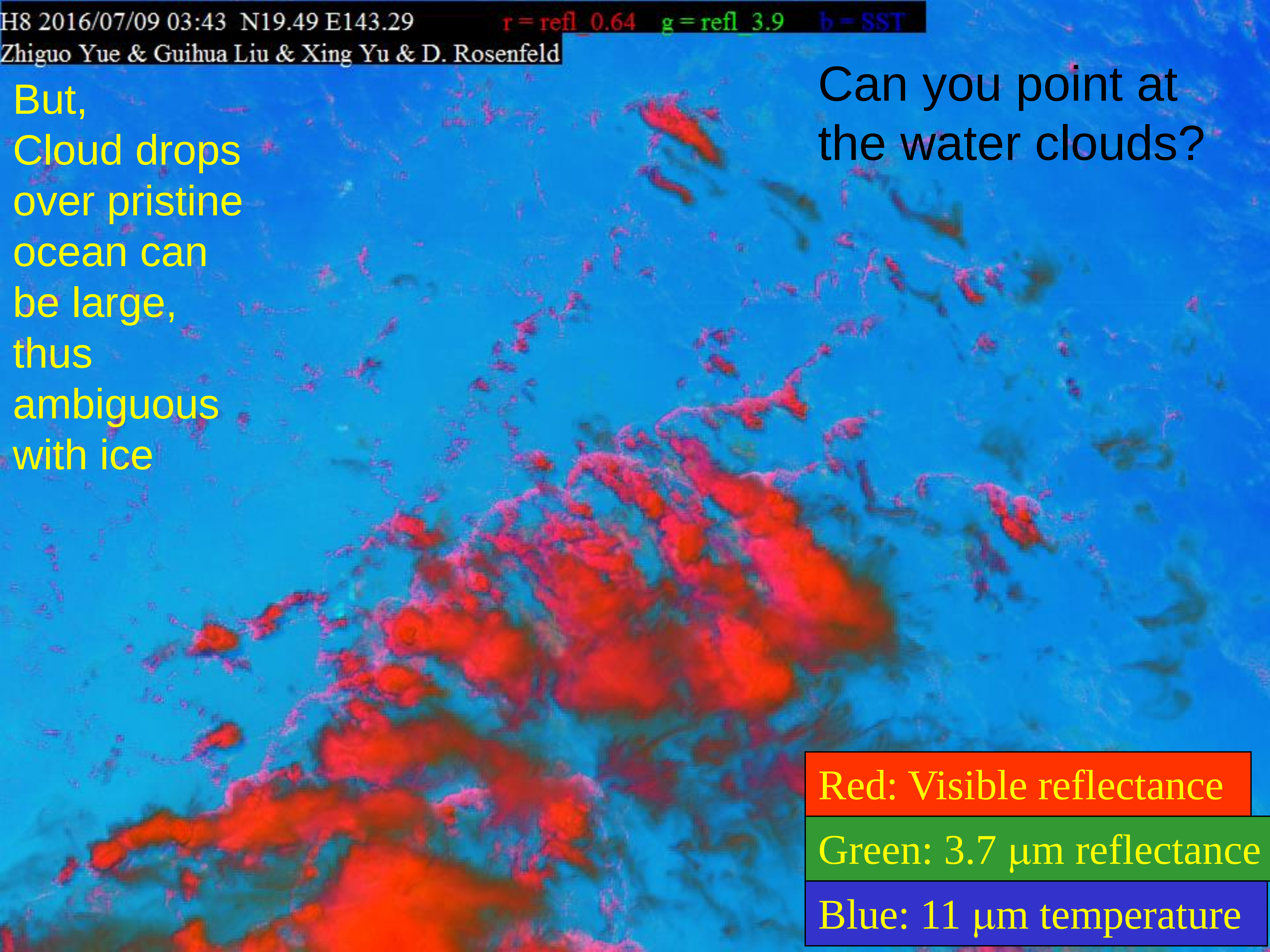

2003/12/19 12:12
CH02 0.8
CH04 A3.9
CH05 10.8
Animation 8/9
0.8 µm
3.9r µm
10.8 µm

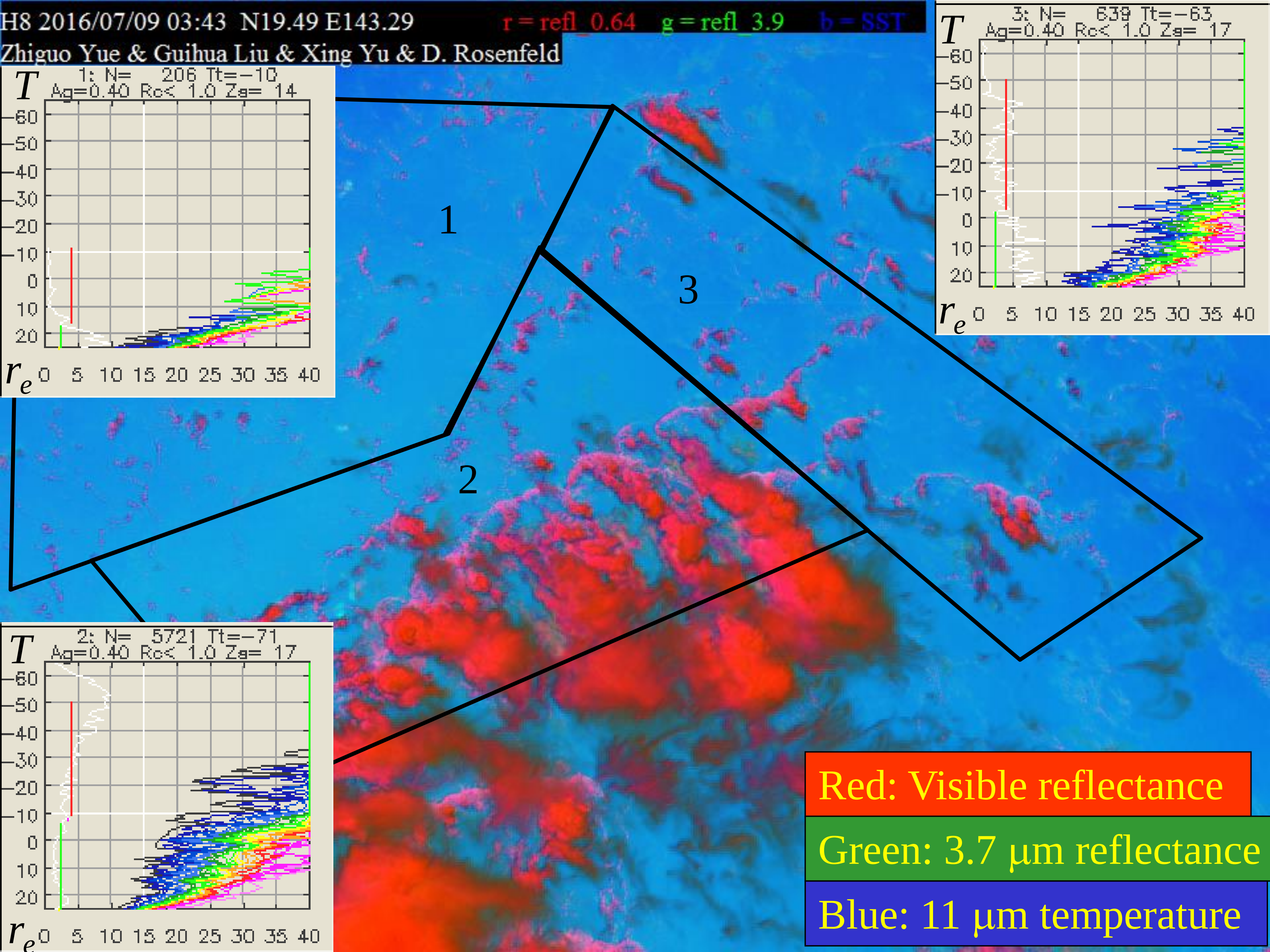
Animation 9/9



But,
Cloud drops over pristine ocean can be large, thus ambiguous with ice

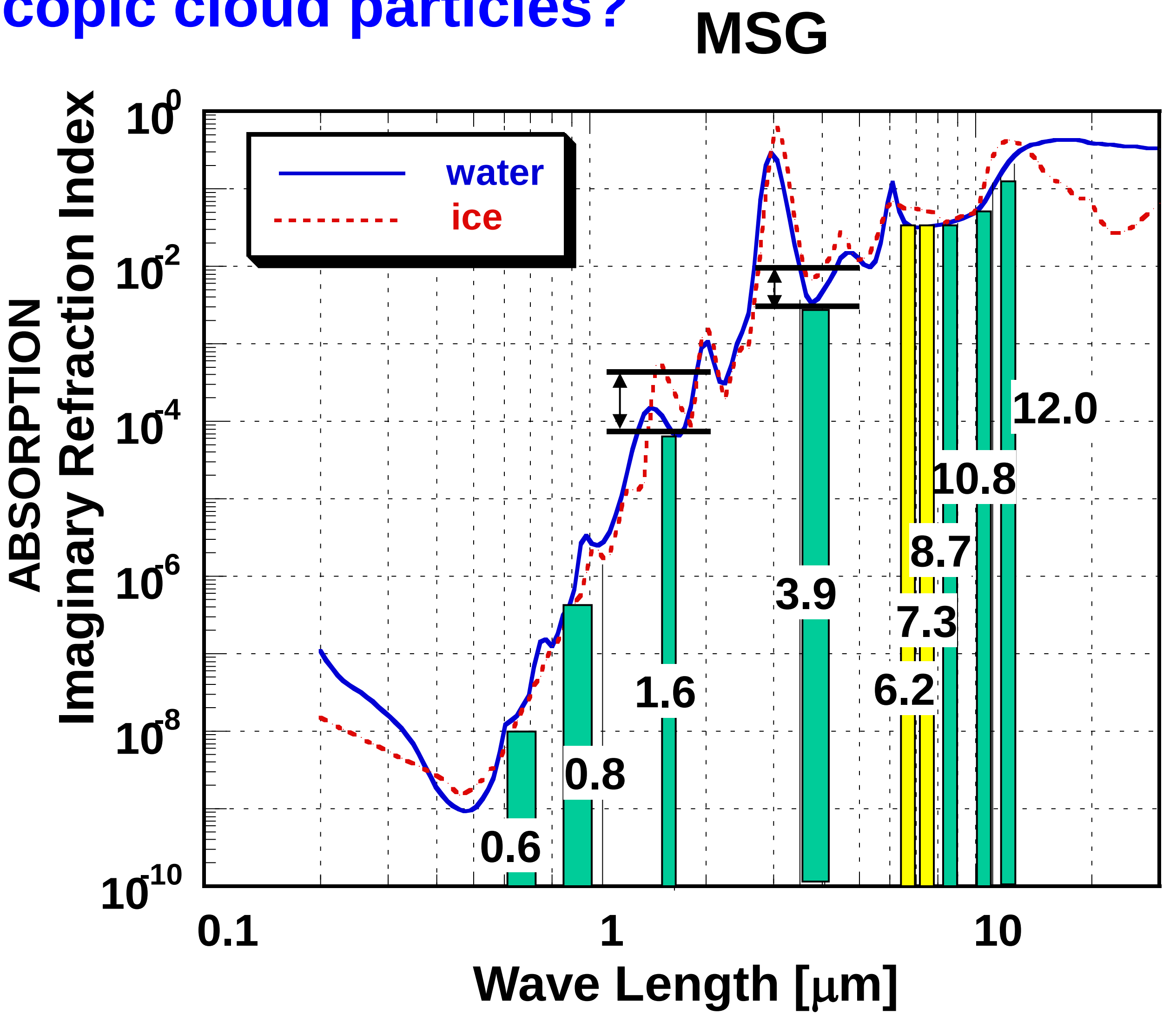



H8 2016/07/09 03:43 N19.49 E143.29
r = refl_0.64 g = refl_3.9 b = SST
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld
But,
Cloud drops over pristine ocean can be large, thus ambiguous with ice
Can you point at the water clouds?
Red: Visible reflectance
Green: 3.7 μm reflectance
Blue: 11 μm temperature



H8 2016/07/09 03:43 N19.49 E143.29
r = refl_0.64 g = refl_3.9 b = SST
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld
1: N= 206 Tt=-10
Ag=0.40 Rc< 1.0 Zg= 14
2: N= 5721 Tt=-71
Ag=0.40 Rc< 1.0 Zg= 17
3: N= 639 Tt=-63
Ag=0.40 Rc< 1.0 Zg= 17
1
2
3
Red: Visible reflectance
Green: 3.7 μm reflectance
Blue: 11 μm temperature

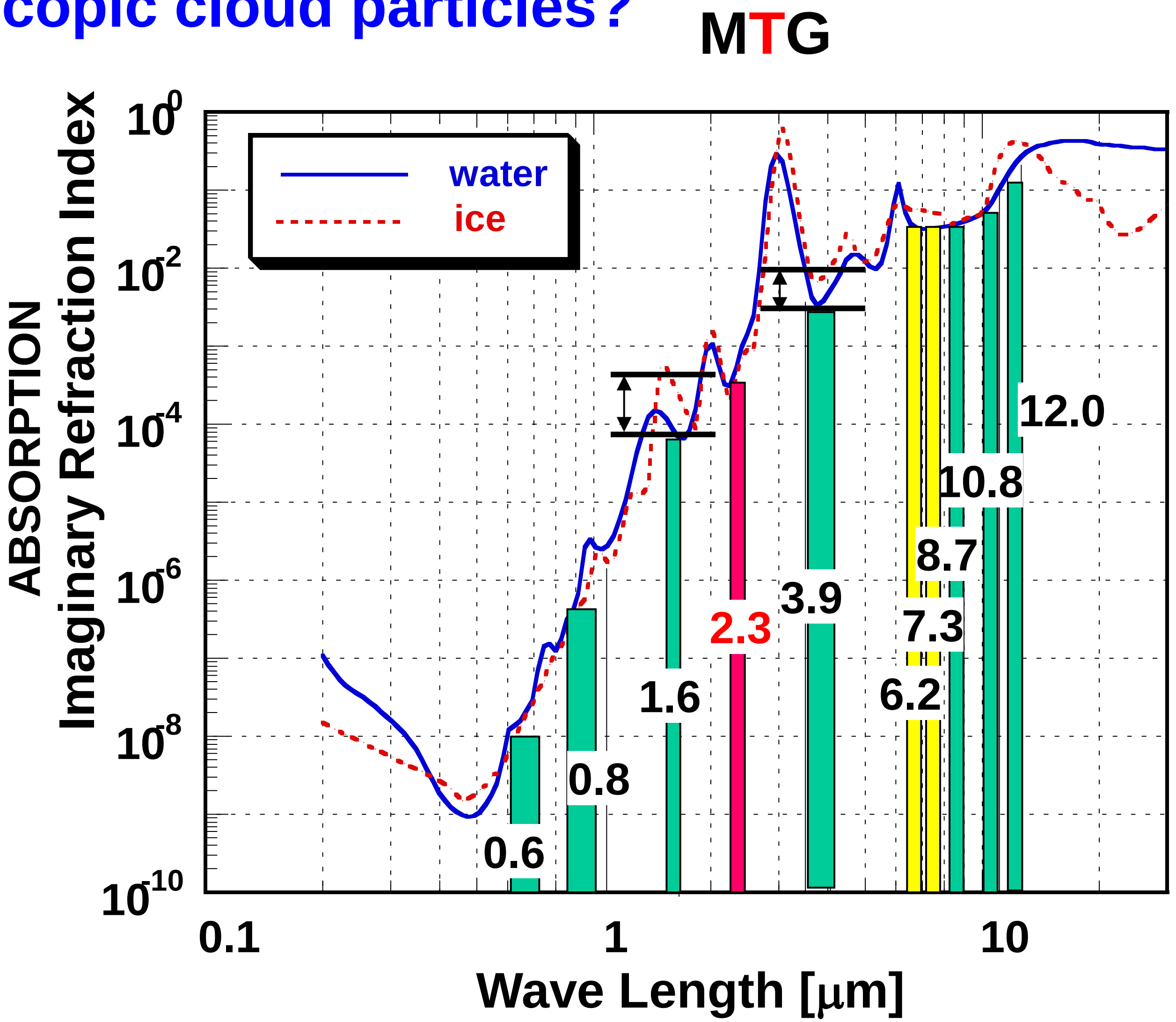
How can we detect from space the phase and size of microscopic cloud particles?



Slide 29

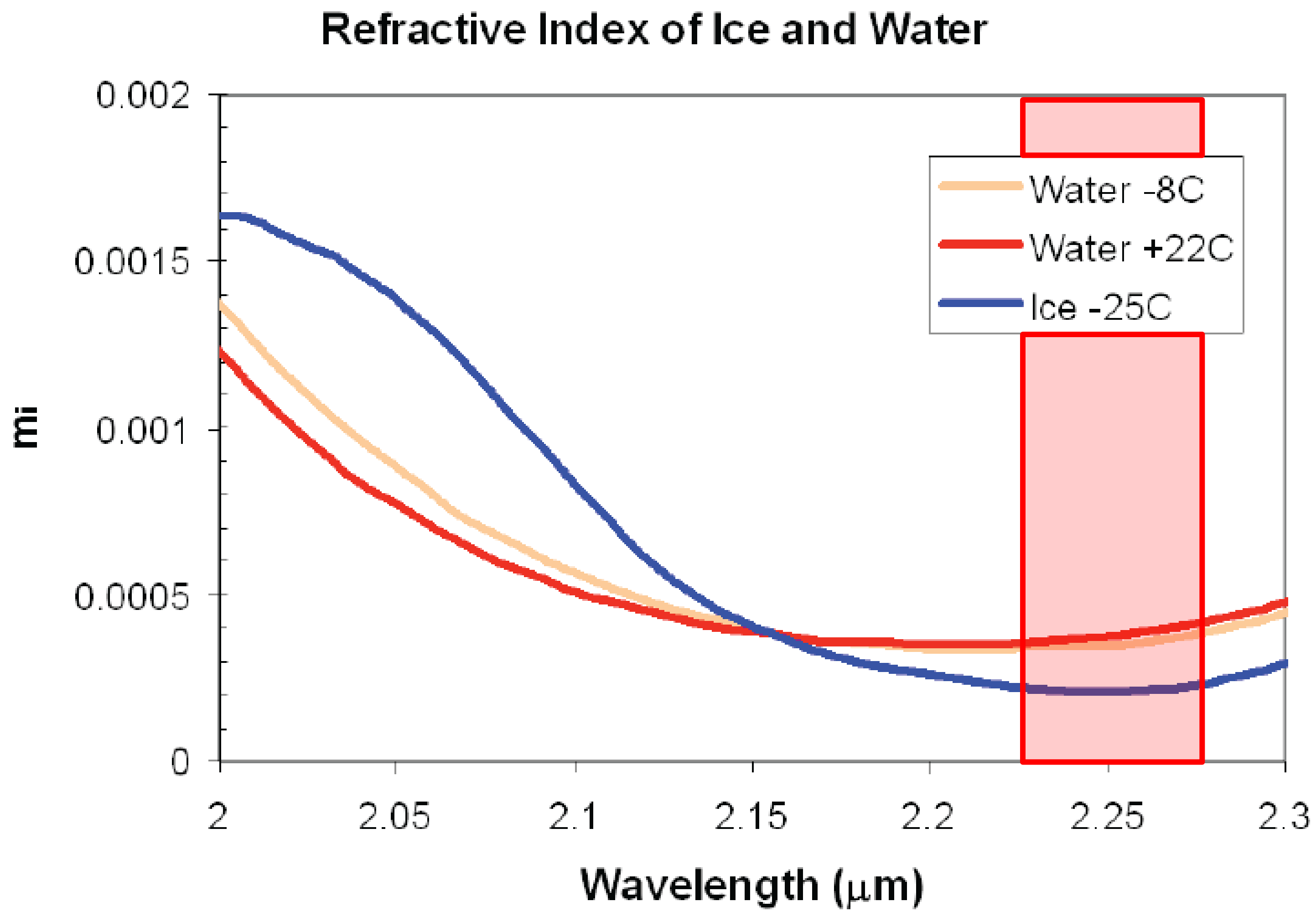
Channel 4, 3.9 µm, absorbs even more solar radiation than Channel 3, 1.6 µm. Ice absorbs more strongly than water at 3.9 µm.

How can we detect from space the phase and size of microscopic cloud particles?



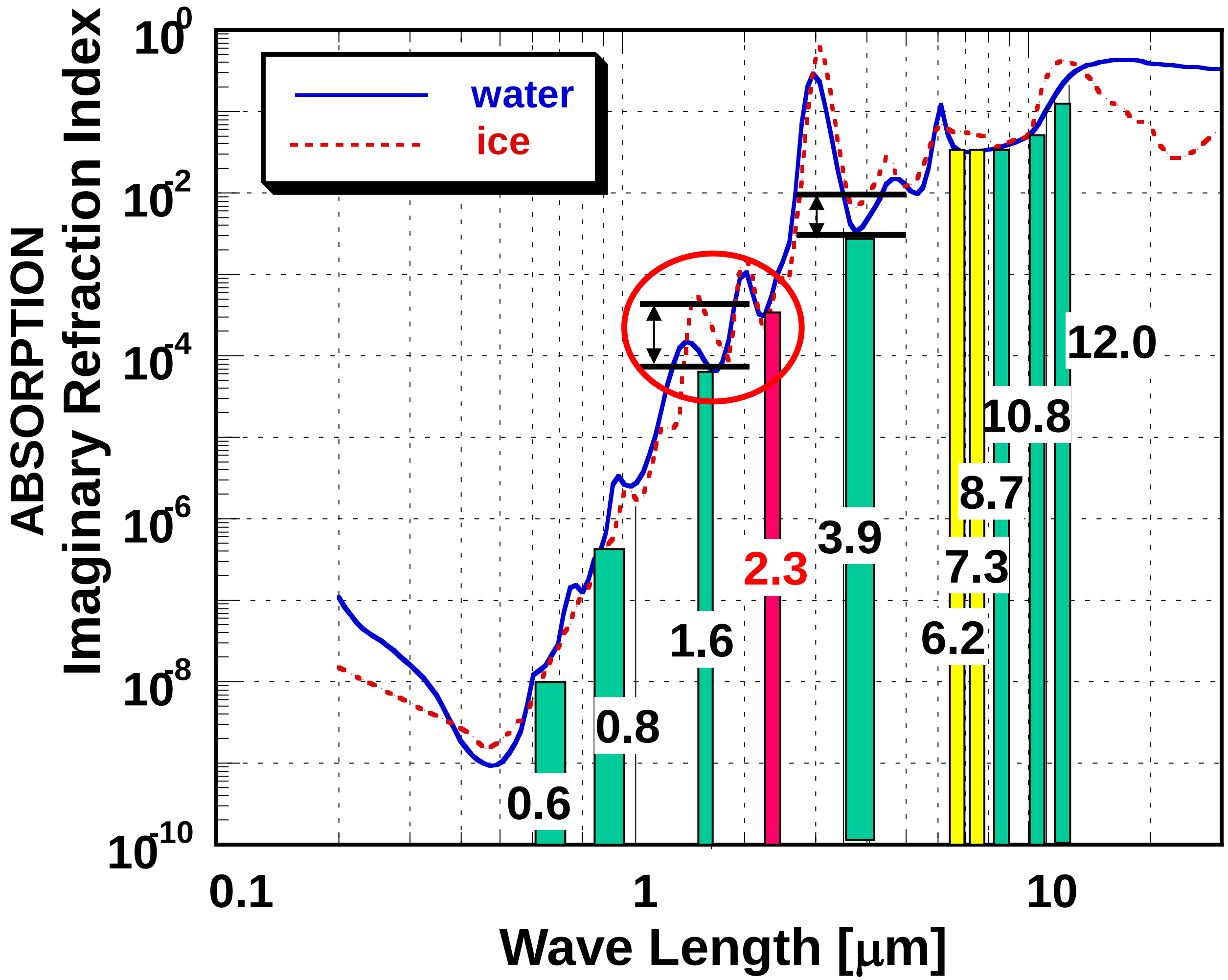
Slide 30

Channel 4, 3.9 μm, absorbs even more solar radiation than Channel 3, 1.6 μm. Ice absorbs more strongly than water at 3.9 μm.



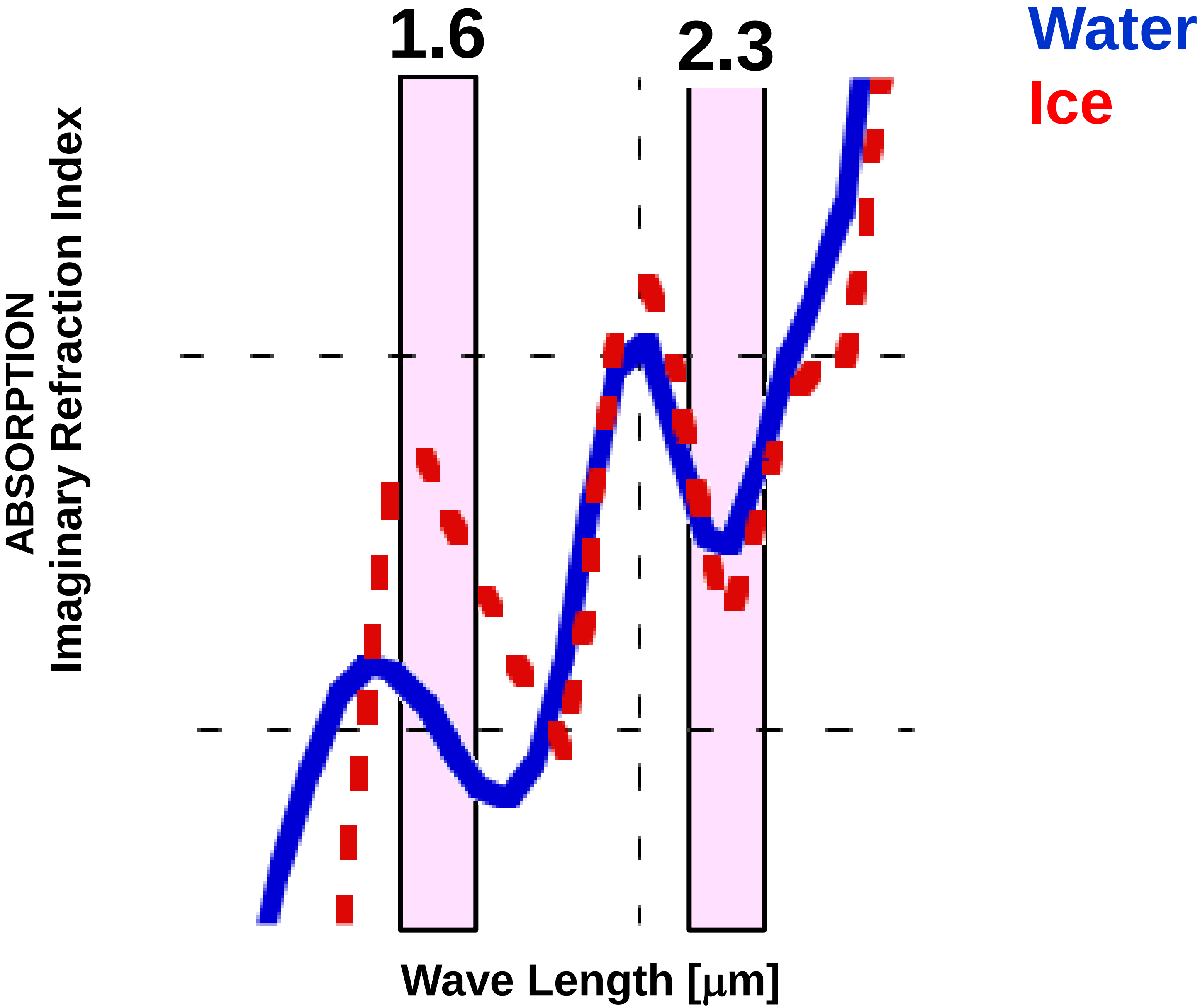
The spectral dependence of the imaginary component of the refractive indices of ice and water between 2.0 and 2.3 μm, showing the crossing point around 2.15 μm.

How can we detect from space the phase and size of microscopic cloud particles?

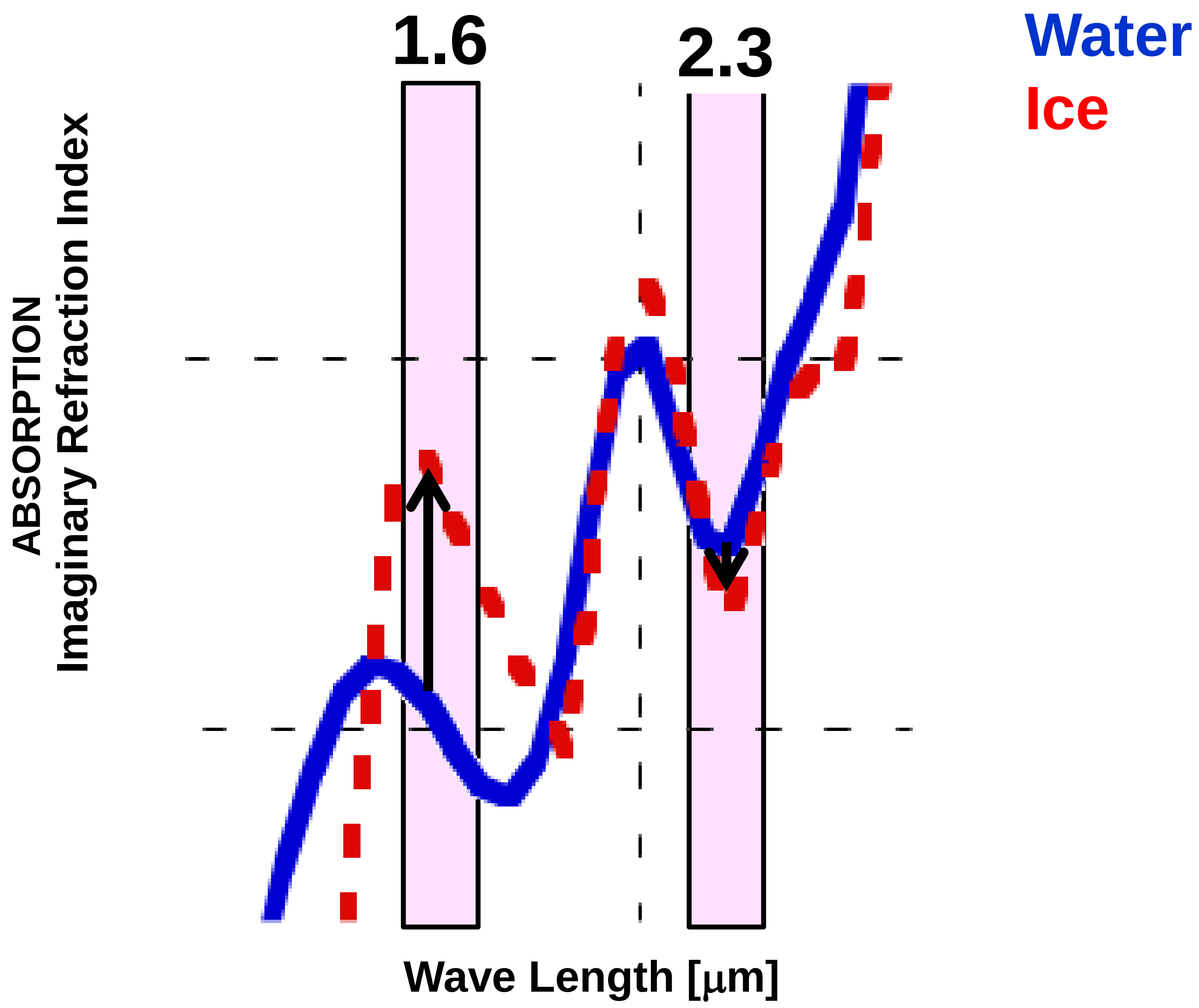


Slide 32

Channel 4, 3.9 μm, absorbs even more solar radiation than Channel 3, 1.6 μm. Ice absorbs more strongly than water at 3.9 μm.



1.6
2.3
Water
Ice
ABSORPTION
Imaginary Refraction Index
Wave Length [μm]


1.6
2.3
Water
Ice
ABSORPTION
Imaginary Refraction Index
Wave Length [μm]

CHANNEL MTG	CENTRE WAVELENGTH	SPECTRAL WIDTH	SPATIAL SAMPLING DISTANCE (SSD)
VIS 0.4	0.444 μm	0.060 μm	1.0 km
VIS 0.5	0.510 μm	0.040 μm	1.0 km
VIS 0.6	0.640 μm	0.050 μm	1.0 km; 0.5 km*
VIS 0.8	0.865 μm	0.050 μm	1.0 km
VIS 0.9	0.914 μm	0.020 μm	1.0 km
NIR 1.3	1.380 μm	0.030 μm	1.0 km
NIR 1.6	1.610 μm	0.050 μm	1.0 km
NIR 2.2	2.250 μm	0.050 μm	1.0 km; 0.5 km*
IR 3.8 (TIR)	3.800 μm	0.400 μm	2.0 km; 1.0 km*
WV 6.3	6.300 μm	1.000 μm	2.0 km
WV 7.3	7.350 μm	0.500 μm	2.0 km
IR 8.7 (TIR)	8.700 μm	0.400 μm	2.0 km
IR 9.7 (O_3)	9.660 μm	0.300 μm	2.0 km
IR 10.5 (TIR)	10.500 μm	0.700 μm	2.0 km; 1.0 km*
IR 12.3 (TIR)	12.300 μm	0.500 μm	2.0 km
IR 13.3 (CO_2)	13.300 μm	0.600 μm	2.0 km

Note: *The channels VIS 0.6, NIR 2.2, IR 3.8 and IR 10.5 are delivered in both FDS and RRS sampling configurations, the latter is indicated by * in the table.*

CHANNEL MTG	CENTRE WAVELENGTH	SPECTRAL WIDTH	SPATIAL SAMPLING DISTANCE (SSD)
VIS 0.4	0.444 μm	0.060 μm	1.0 km
VIS 0.5	0.510 μm	0.040 μm	1.0 km
VIS 0.6	0.640 μm	0.050 μm	1.0 km; 0.5 km*
VIS 0.8	0.865 μm	0.050 μm	1.0 km
VIS 0.9	0.914 μm	0.020 μm	1.0 km
NIR 1.3	1.380 μm	0.030 μm	1.0 km
NIR 1.6	1.610 μm	0.050 μm	1.0 km
NIR 2.2	2.250 μm	0.050 μm	1.0 km; 0.5 km*
IR 3.8 (TIR)	3.800 μm	0.400 μm	2.0 km; 1.0 km*
WV 6.3	6.300 μm	1.000 μm	2.0 km
WV 7.3	7.350 μm	0.500 μm	2.0 km
IR 8.7 (TIR)	8.700 μm	0.400 μm	2.0 km
IR 9.7 (O_3)	9.660 μm	0.300 μm	2.0 km
IR 10.5 (TIR)	10.500 μm	0.700 μm	2.0 km; 1.0 km*
IR 12.3 (TIR)	12.300 μm	0.500 μm	2.0 km
IR 13.3 (CO_2)	13.300 μm	0.600 μm	2.0 km

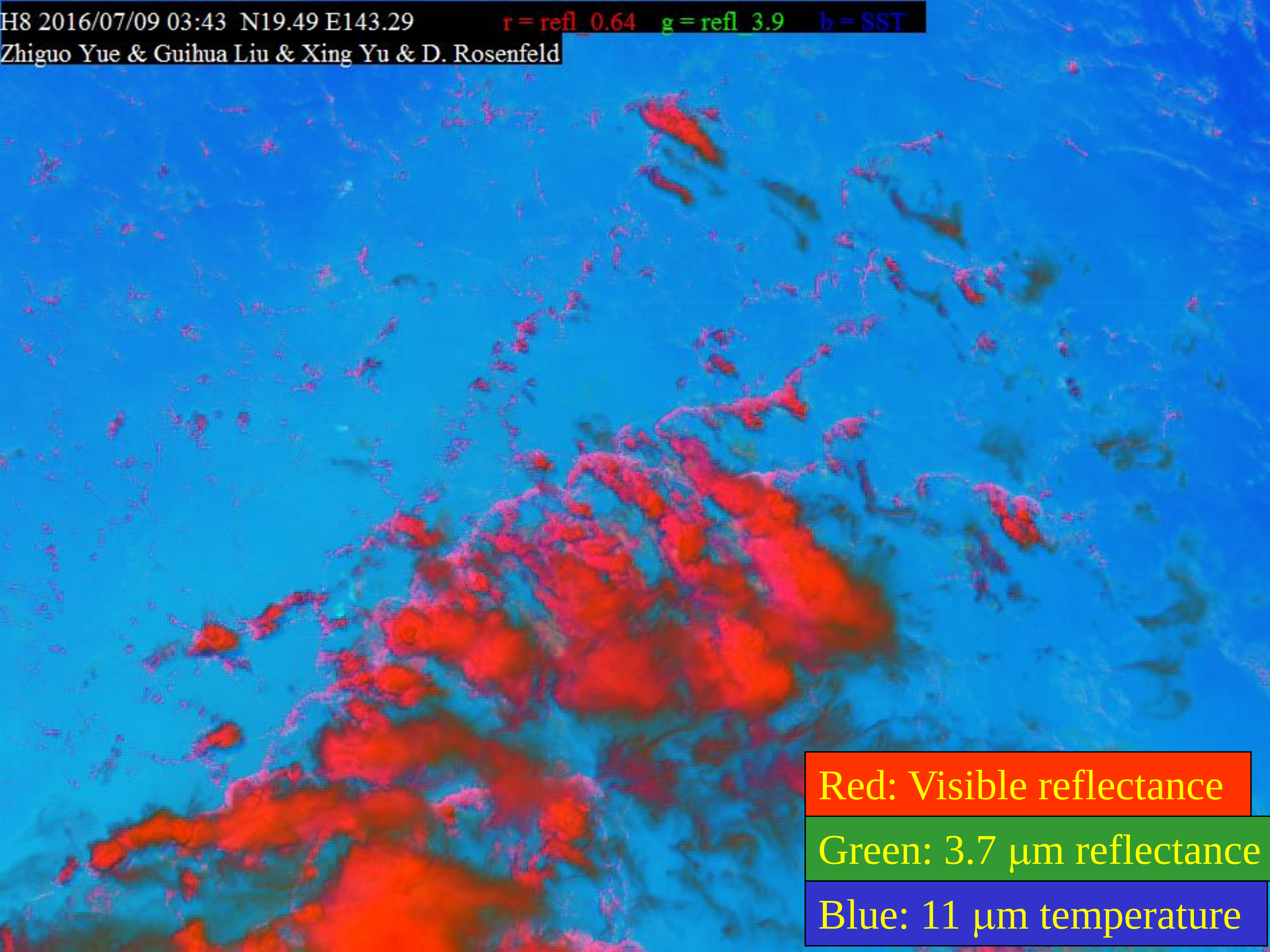
Note: *The channels VIS 0.6, NIR 2.2, IR 3.8 and IR 10.5 are delivered in both FDS and RRS sampling configurations, the latter is indicated by * in the table.*

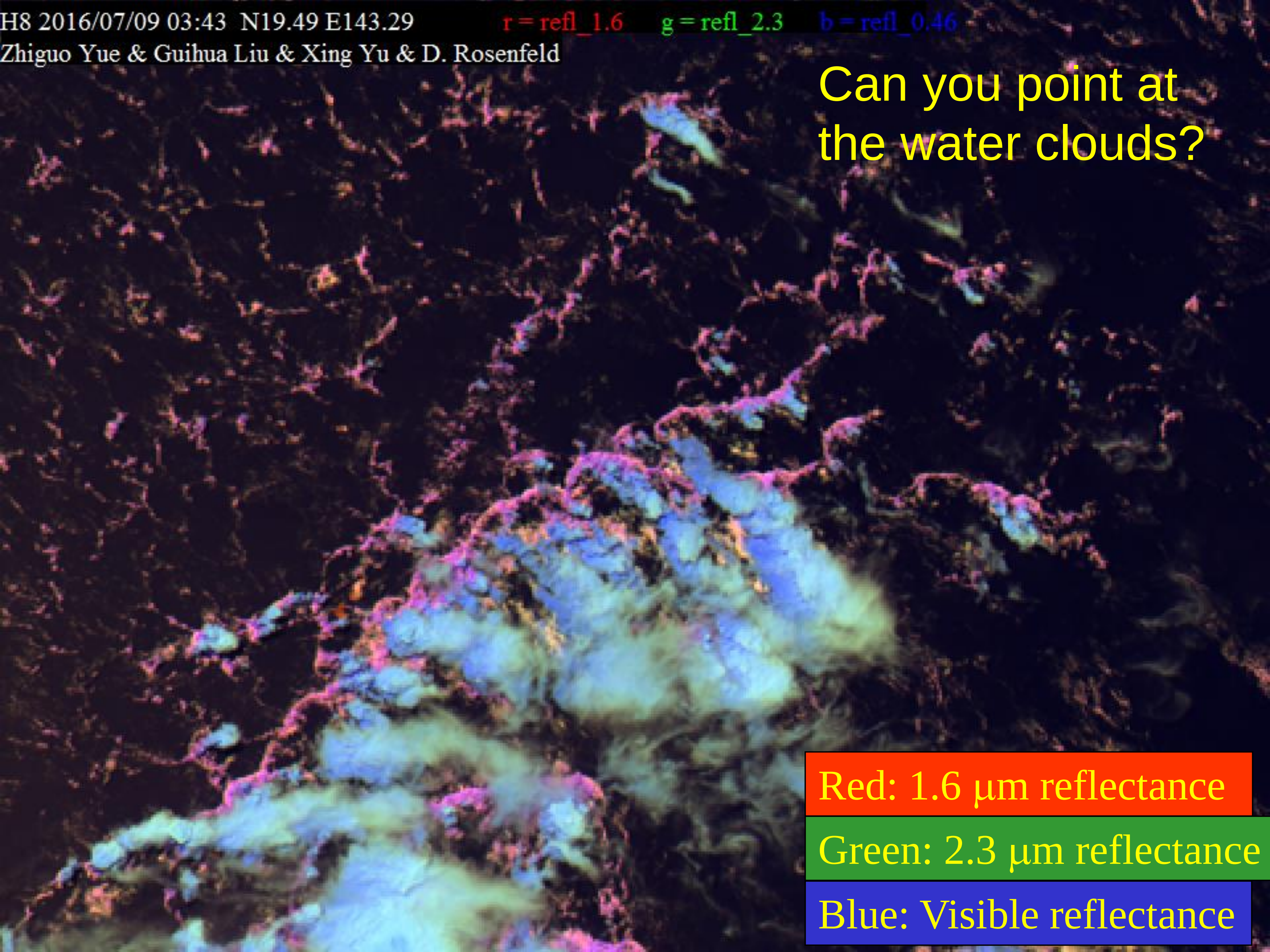
CHANNEL MTG	CENTRE WAVELENGTH	SPECTRAL WIDTH	SPATIAL SAMPLING DISTANCE (SSD)
VIS 0.4	0.444 µm	0.060 µm	1.0 km
VIS 0.5	0.510 µm	0.040 µm	1.0 km
VIS 0.6	0.640 µm	0.050 µm	1.0 km; 0.5 km*
VIS 0.8	0.865 µm	0.050 µm	1.0 km
VIS 0.9	0.914 µm	0.020 µm	1.0 km
NIR 1.3	1.380 µm	0.030 µm	1.0 km
NIR 1.6	1.610 µm	0.050 µm	1.0 km
NIR 2.2	2.250 µm	0.050 µm	1.0 km; 0.5 km*
IR 3.8 (TIR)	3.800 µm	0.400 µm	2.0 km; 1.0 km*
WV 6.3	6.300 µm	1.000 µm	2.0 km
WV 7.3	7.350 µm	0.500 µm	2.0 km
IR 8.7 (TIR)	8.700 µm	0.400 µm	2.0 km
IR 9.7 (O_3)	9.660 µm	0.300 µm	2.0 km
IR 10.5 (TIR)	10.500 µm	0.700 µm	2.0 km; 1.0 km*
IR 12.3 (TIR)	12.300 µm	0.500 µm	2.0 km
IR 13.3 (CO_2)	13.300 µm	0.600 µm	2.0 km

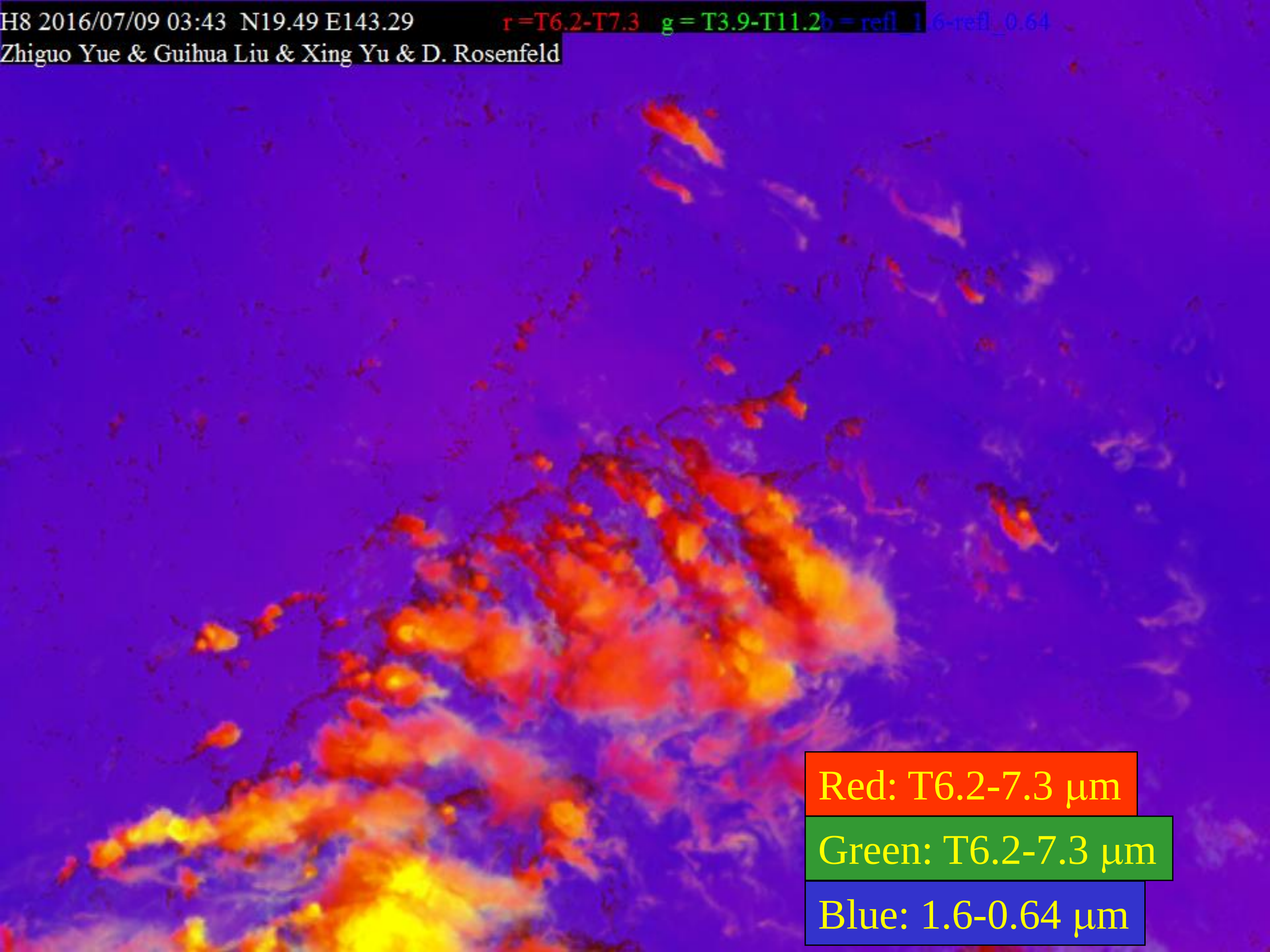
Note: *The channels VIS 0.6, NIR 2.2, IR 3.8 and IR 10.5 are delivered in both FDS and RRS sampling configurations, the latter is indicated by * in the table.*

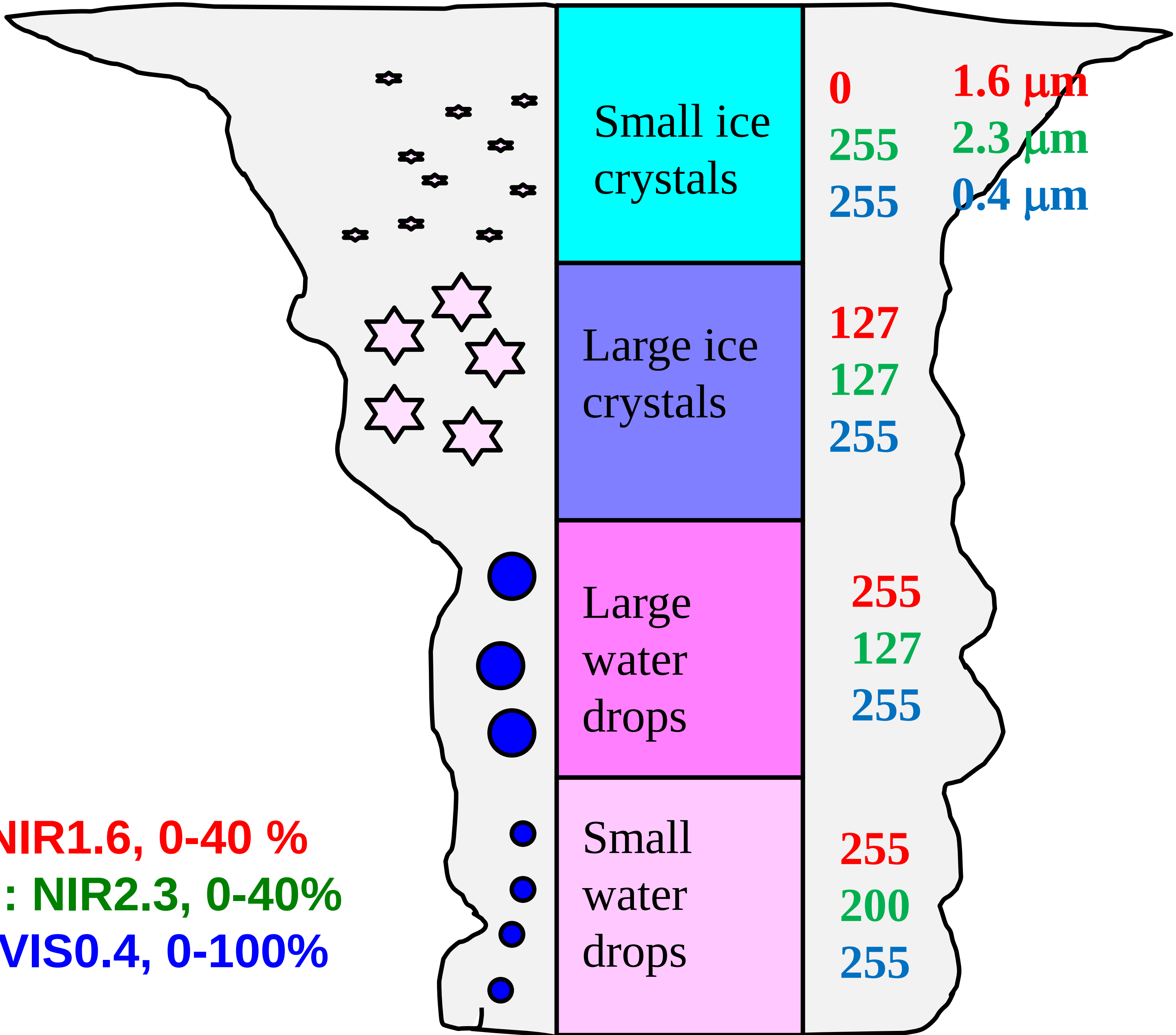
Himawari

Wave length [μm]	Himawari-8/9				MTSAT-1R/2	
	Band number	Spatial resolution at SSP [km]	Central wave length [μm]		Channel name	Spatial resolution at SSP [km]
			AHI-8 (Himawari-8)	AHI-9 (Himawari-9)		
0.47	1	1	0.47063	0.47059	-	-
0.51	2	1	0.51000	0.50993	-	-
0.64	3	0.5	0.63914	0.63972	VIS	1
0.86	4	1	0.85670	0.85668	-	-
1.6	5	2	1.6101	1.6065	-	-
2.3	6	2	2.2568	2.2570	-	-
3.9	7	2	3.8853	3.8289	IR4	4
6.2	8	2	6.2429	6.2479	IR3	4
6.9	9	2	6.9410	6.9555	-	-
7.3	10	2	7.3467	7.3437	-	-
8.6	11	2	8.5926	8.5936	-	-
9.6	12	2	9.6372	9.6274	-	-
10.4	13	2	10.4073	10.4074	IR1	4
11.2	14	2	11.2395	11.2080	-	-
12.4	15	2	12.3806	12.3648	IR2	4
13.3	16	2	13.2807	13.3107	-	-

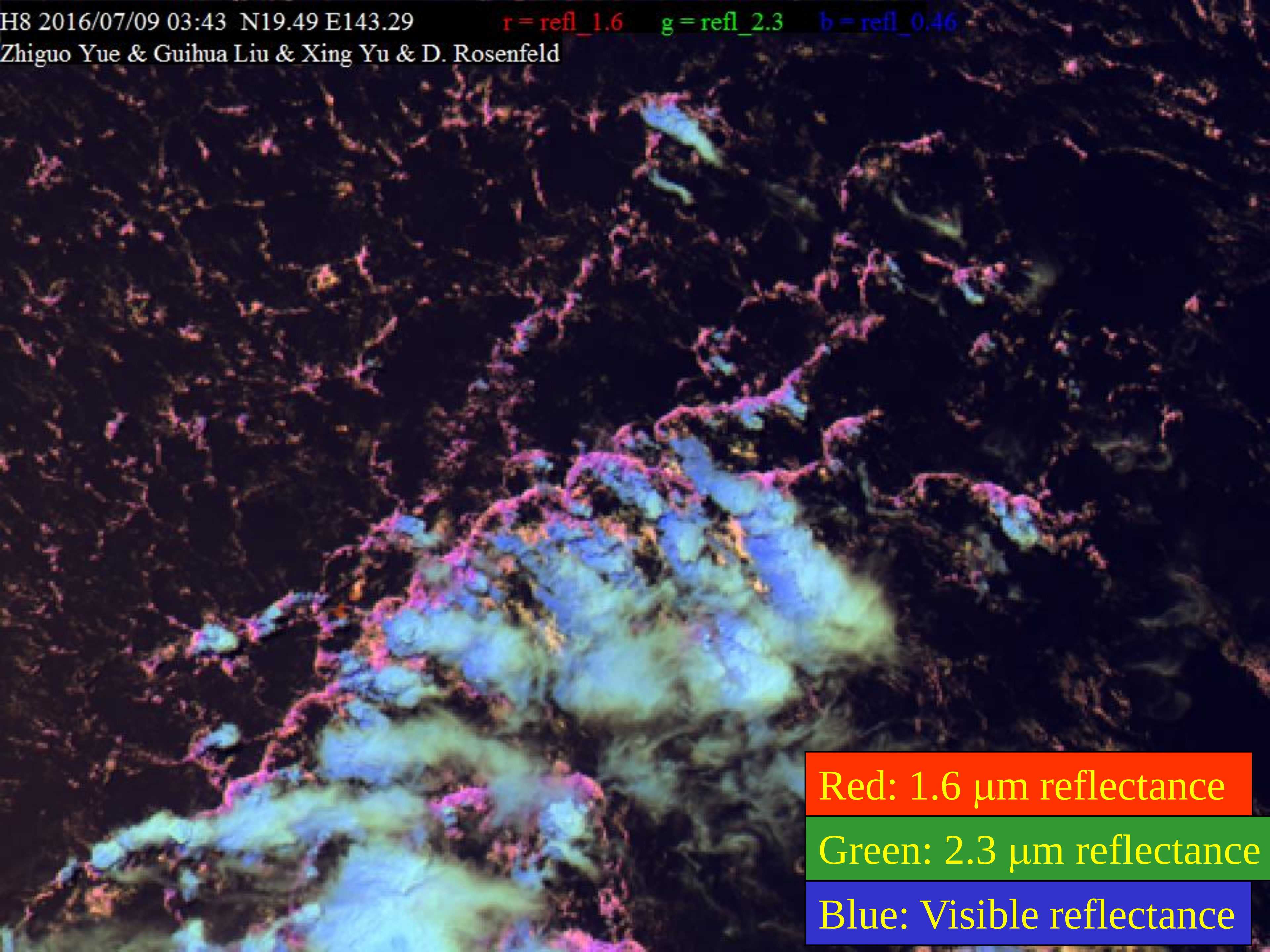

H8 2016/07/09 03:43 N19.49 E143.29
r = refl_0.64
g = refl_3.9
b = SST
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld
Red: Visible reflectance
Green: 3.7 μm reflectance
Blue: 11 μm temperature

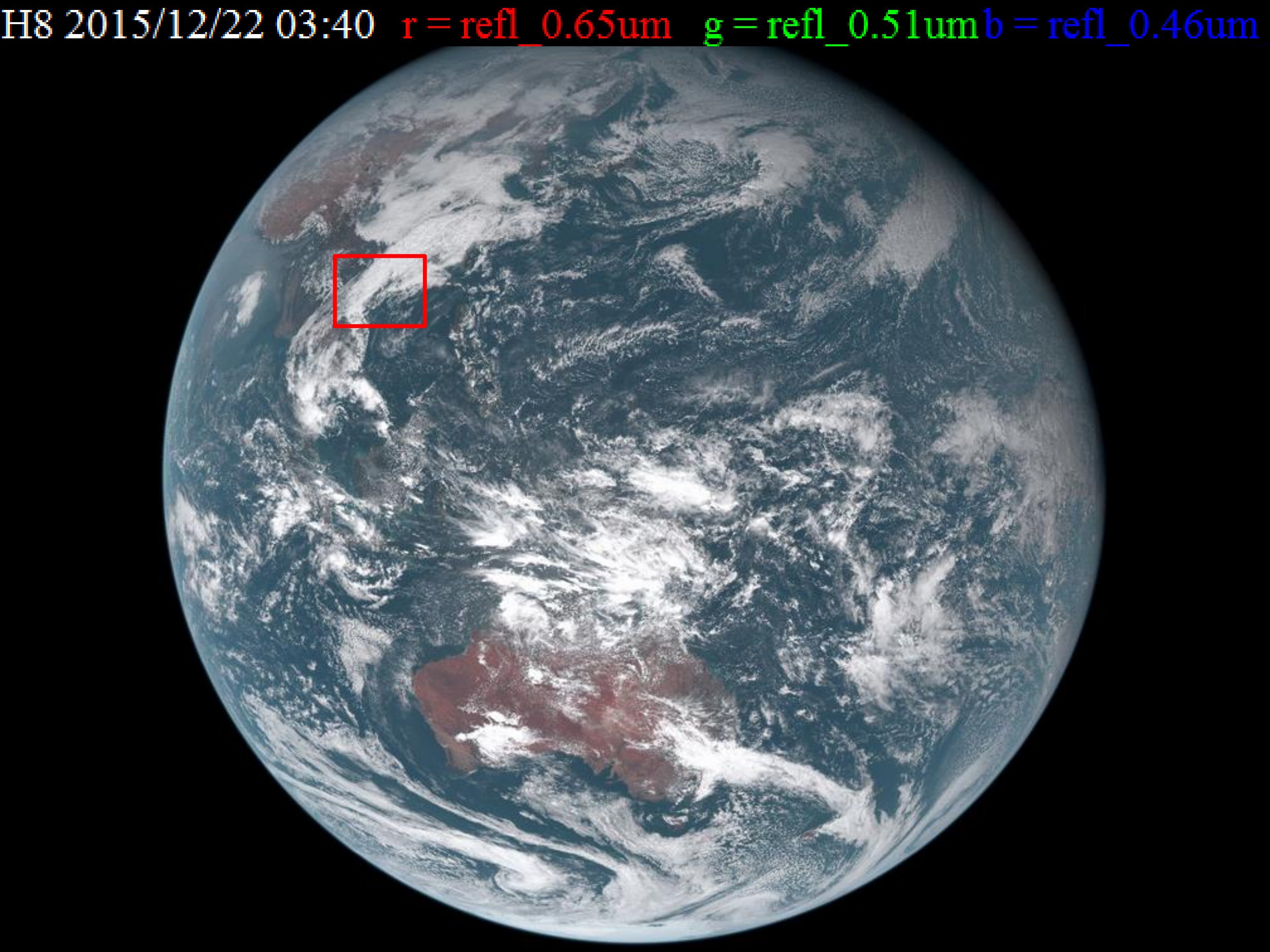

H8 2016/07/09 03:43 N19.49 E143.29
r = refl_1.6
g = refl_2.3
b = refl_0.46
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld
Can you point at the water clouds?
Red: 1.6 µm reflectance
Green: 2.3 µm reflectance
Blue: Visible reflectance

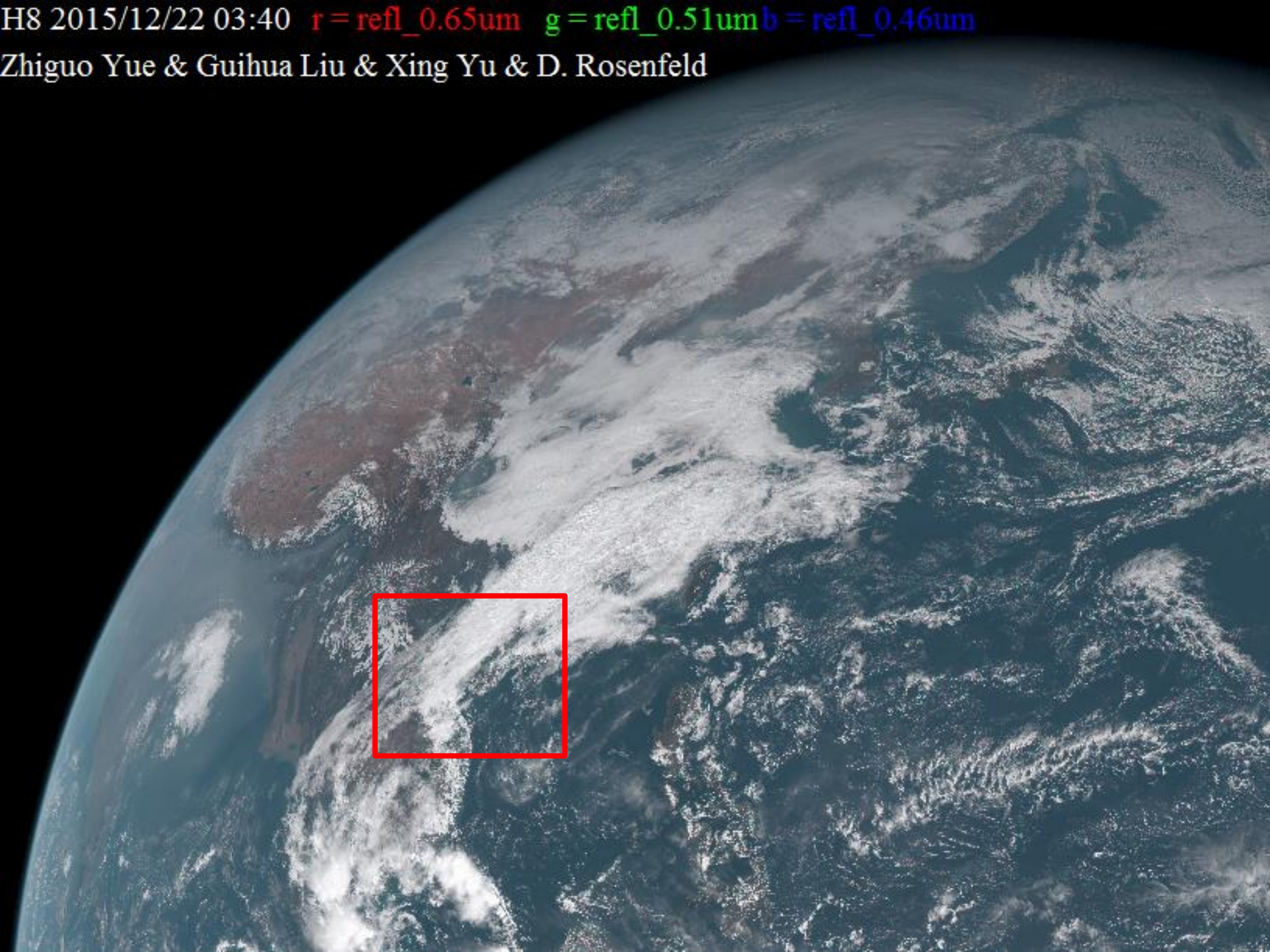

H8 2016/07/09 03:43 N19.49 E143.29
r =T6.2-T7.3 g = T3.9-T11.2 b = refl_1.6-refl_0.64
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld
Red: T6.2-7.3 μm
Green: T6.2-7.3 μm
Blue: 1.6-0.64 μm

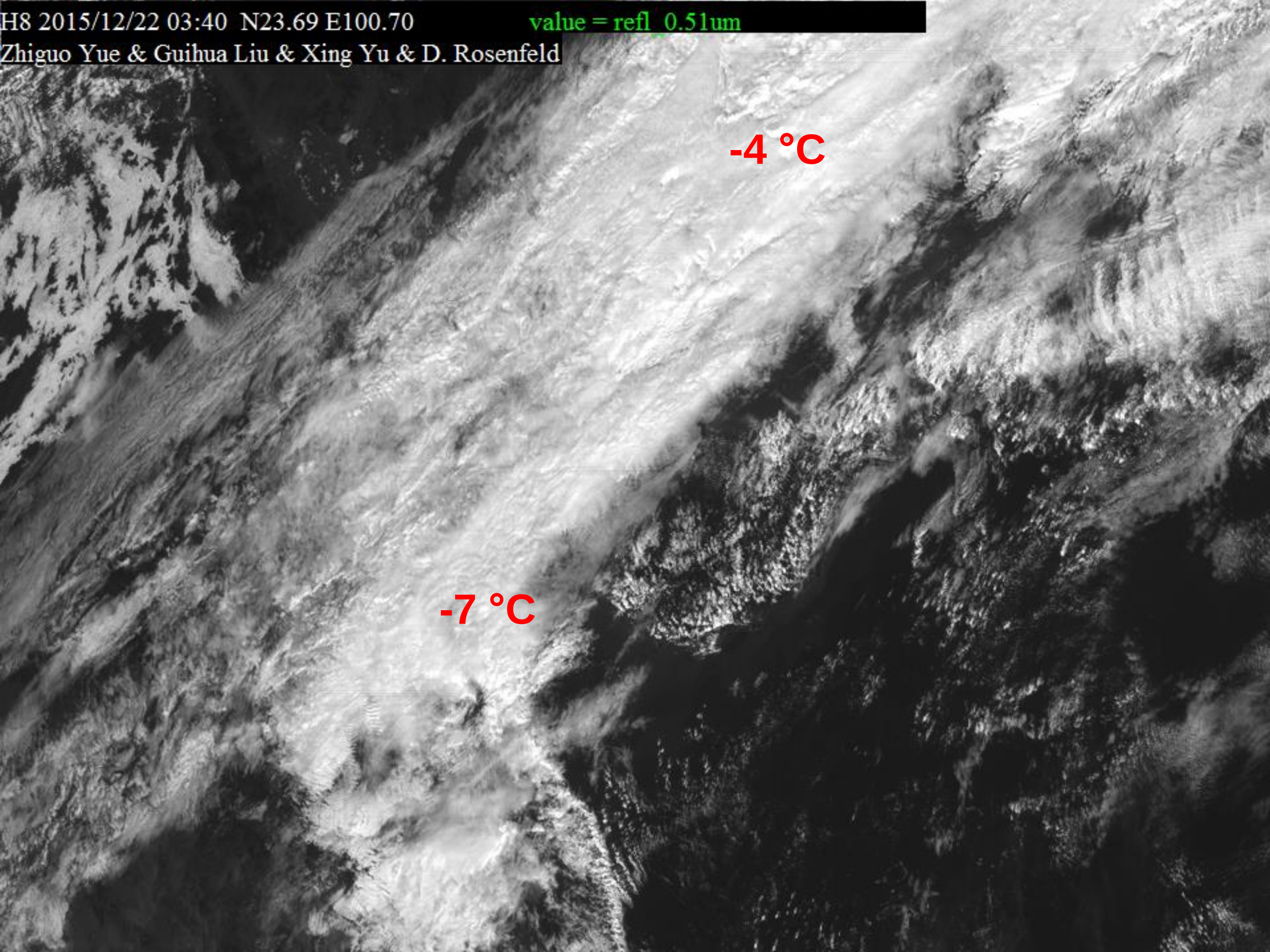


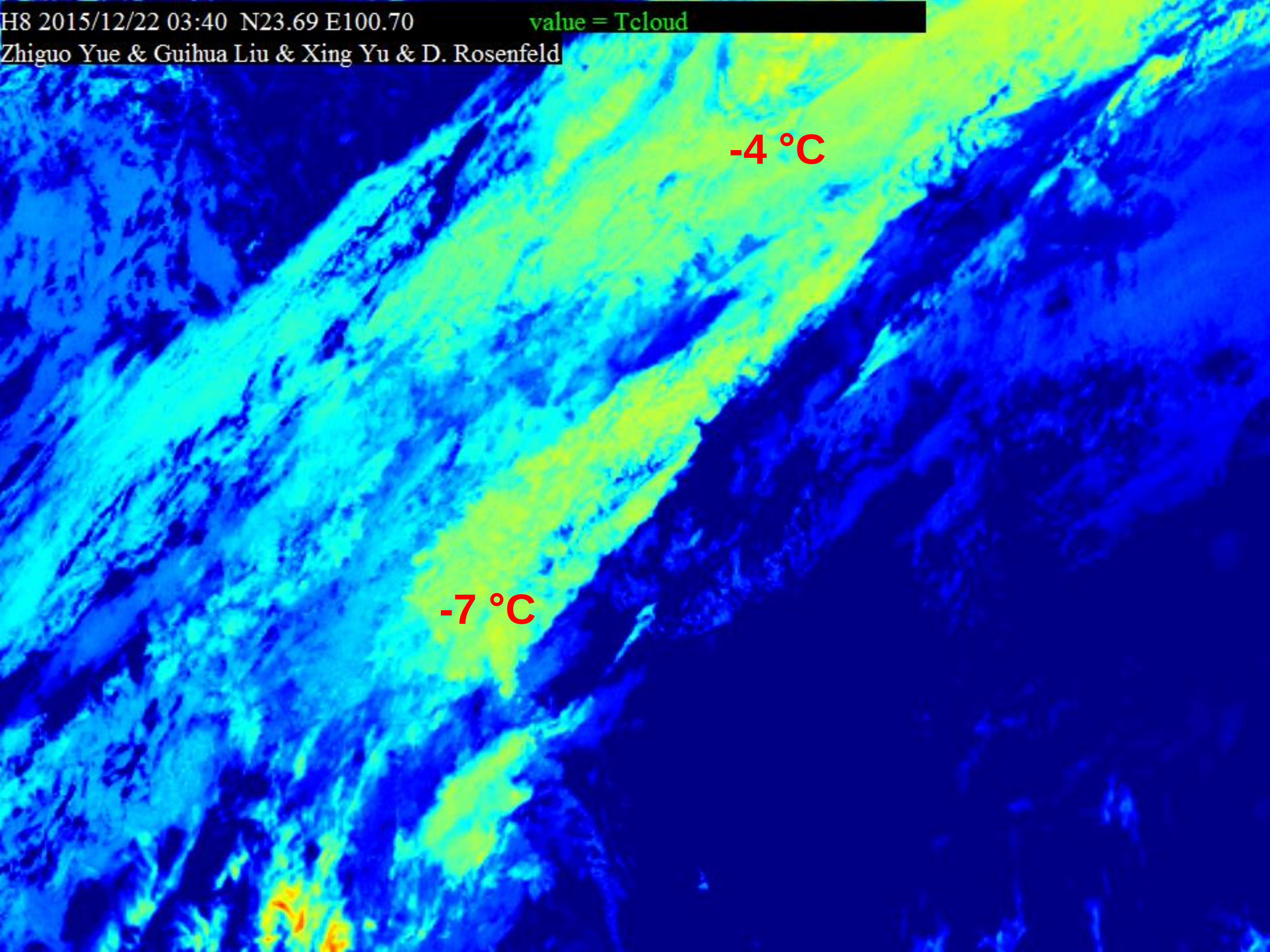
Red: NIR1.6, 0-40 %
Green: NIR2.3, 0-40%
Blue: VIS0.4, 0-100%

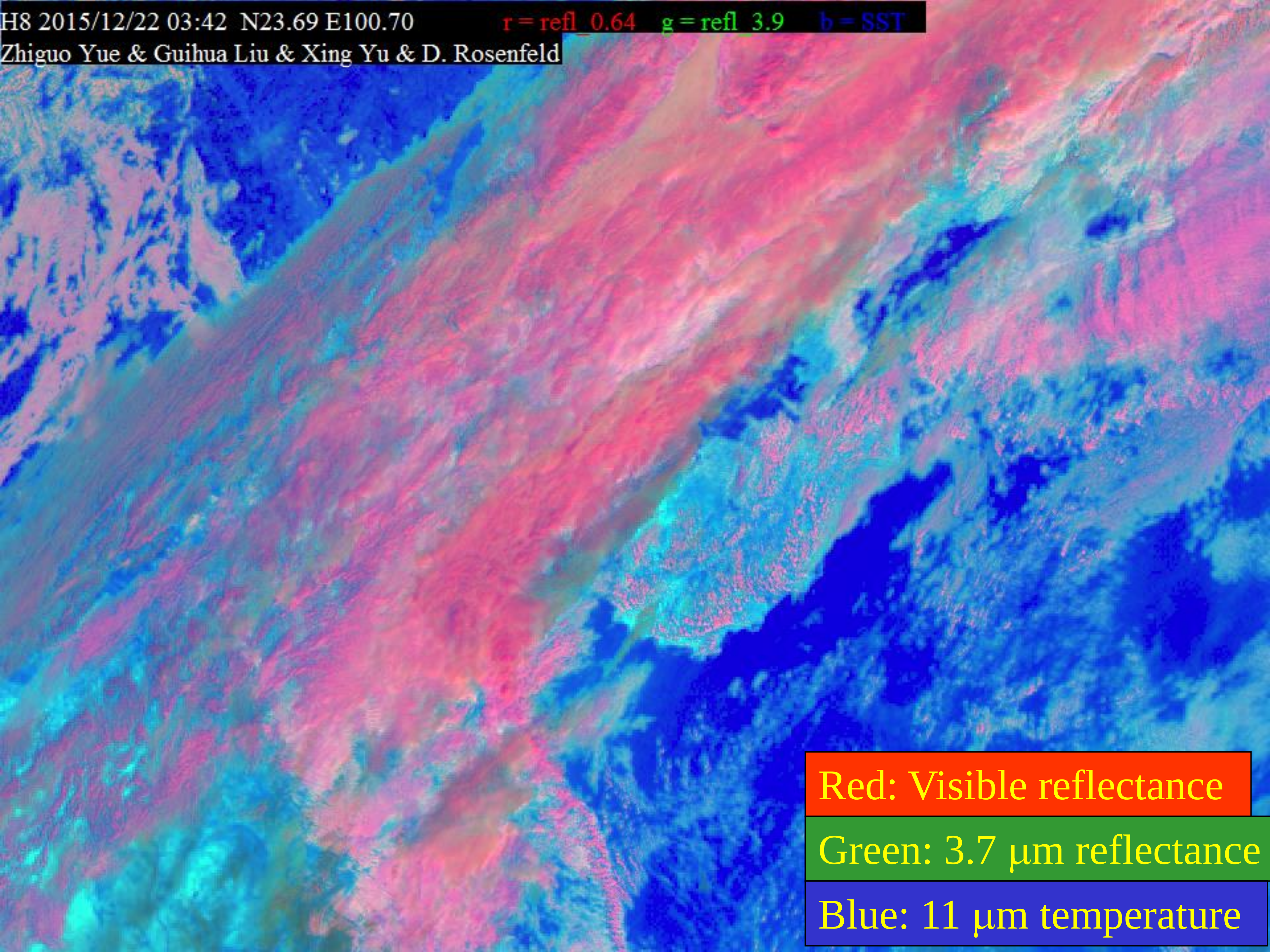

H8 2016/07/09 03:43 N19.49 E143.29
r = refl_1.6
g = refl_2.3
b = refl_0.46
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld
Red: 1.6 μm reflectance
Green: 2.3 μm reflectance
Blue: Visible reflectance

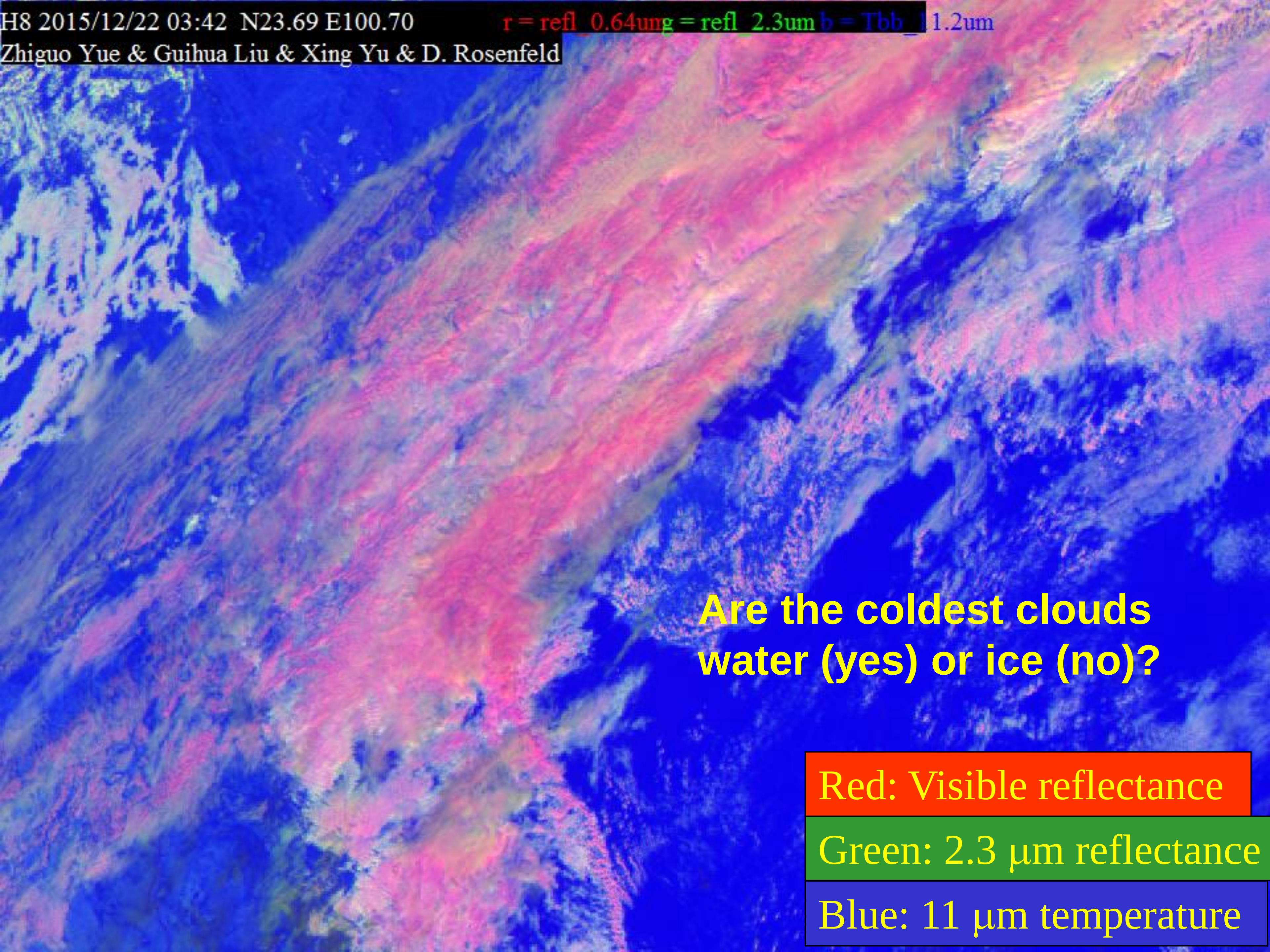

H8 2015/12/22 03:40
r = refl_0.65um
g = refl_0.51um
b = refl_0.46um

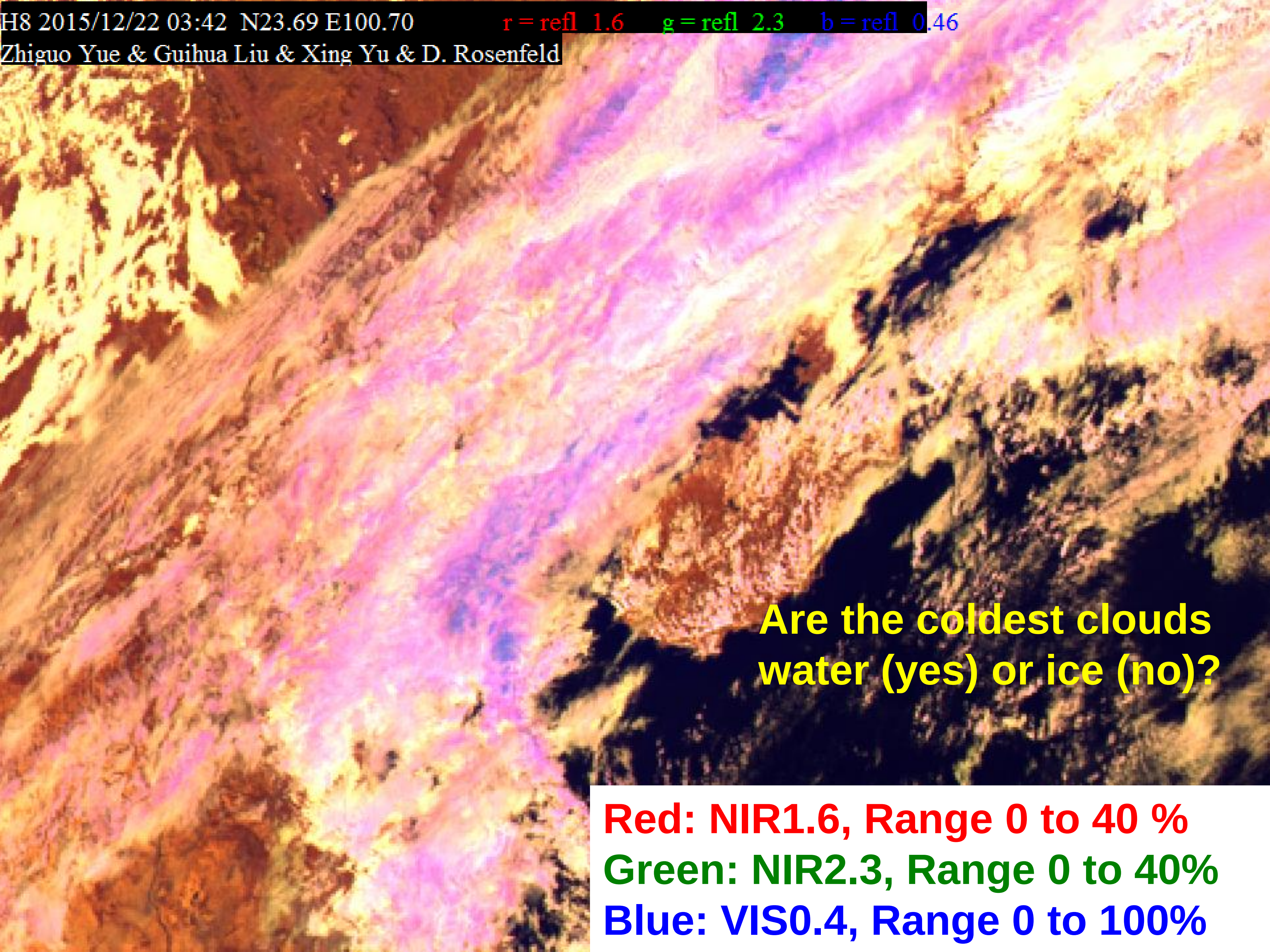

H8 2015/12/22 03:40
r = refl_0.65um
g = refl_0.51um
b = refl_0.46um
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld


H8 2015/12/22 03:40 N23.69 E100.70
value = refl 0.51um
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld
-4 °C
-7 °C

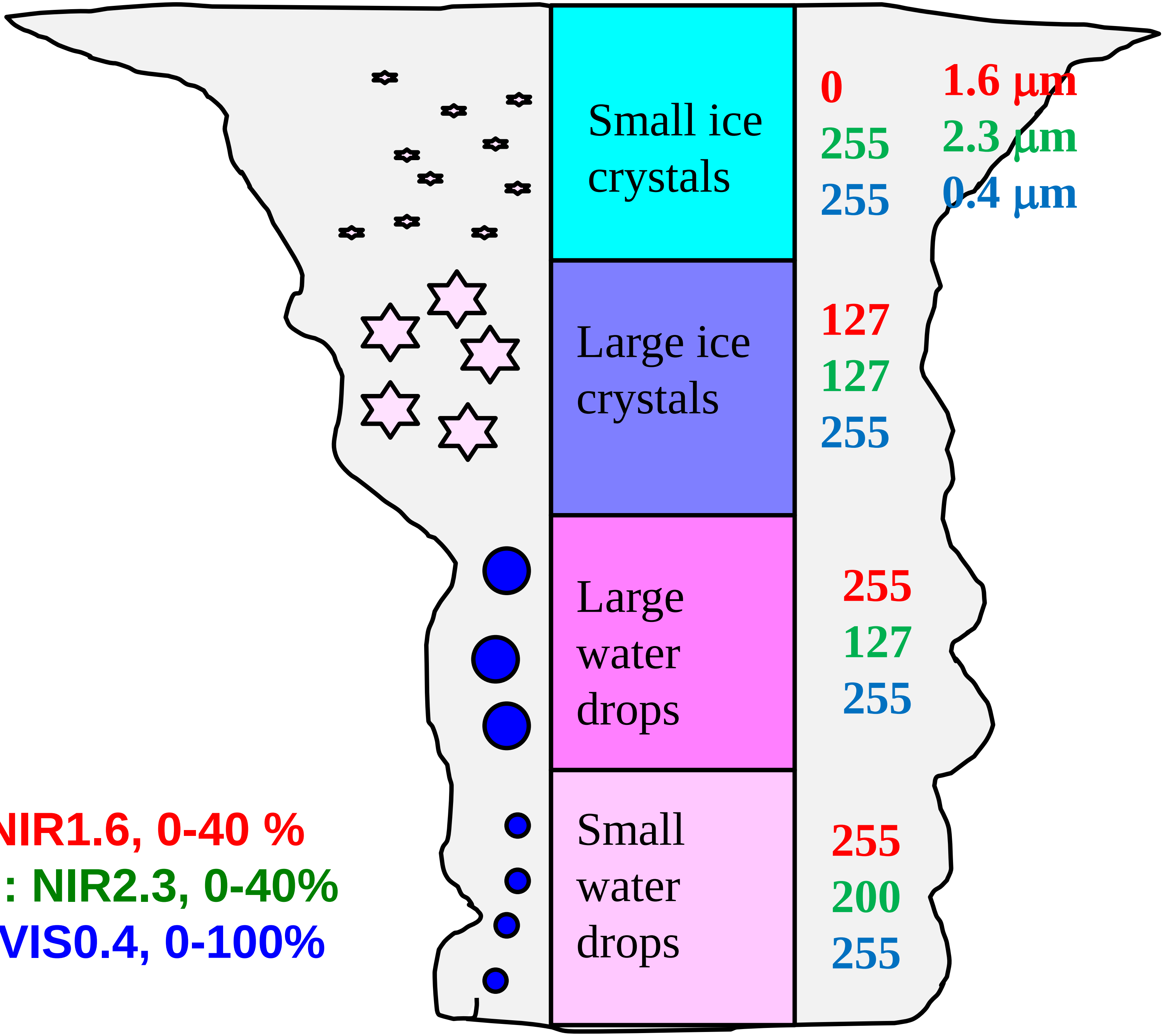

H8 2015/12/22 03:40 N23.69 E100.70
value = Tcloud
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld
-4 °C
-7 °C


H8 2015/12/22 03:42 N23.69 E100.70
r = refl_0.64 g = refl_3.9 b = SST
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld
Red: Visible reflectance
Green: 3.7 μm reflectance
Blue: 11 μm temperature

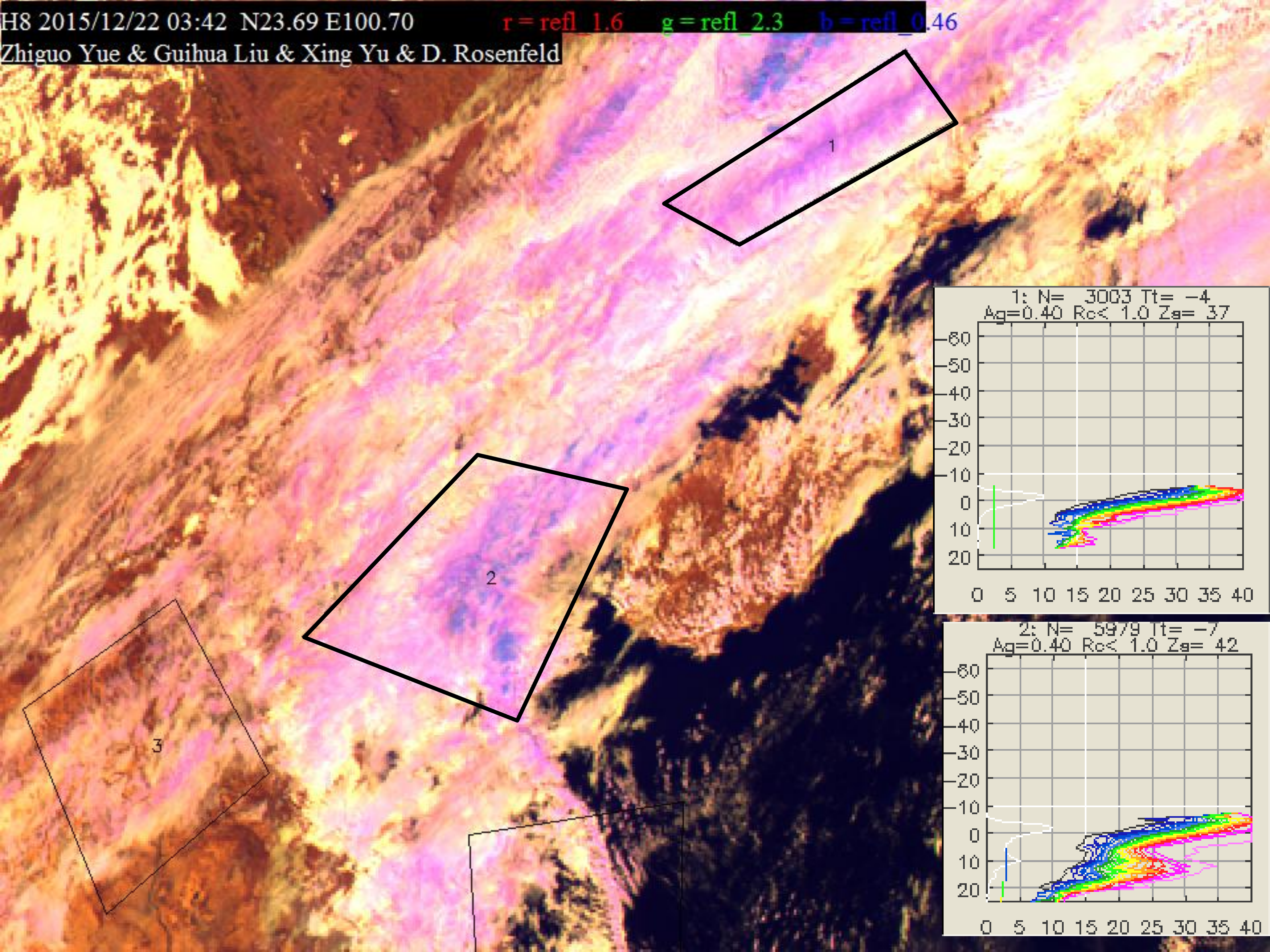

H8 2015/12/22 03:42 N23.69 E100.70
r = refl_0.64um g = refl_2.3um b = Tbb_11.2um
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld
Are the coldest clouds water (yes) or ice (no)?
Red: Visible reflectance
Green: 2.3 µm reflectance
Blue: 11 µm temperature



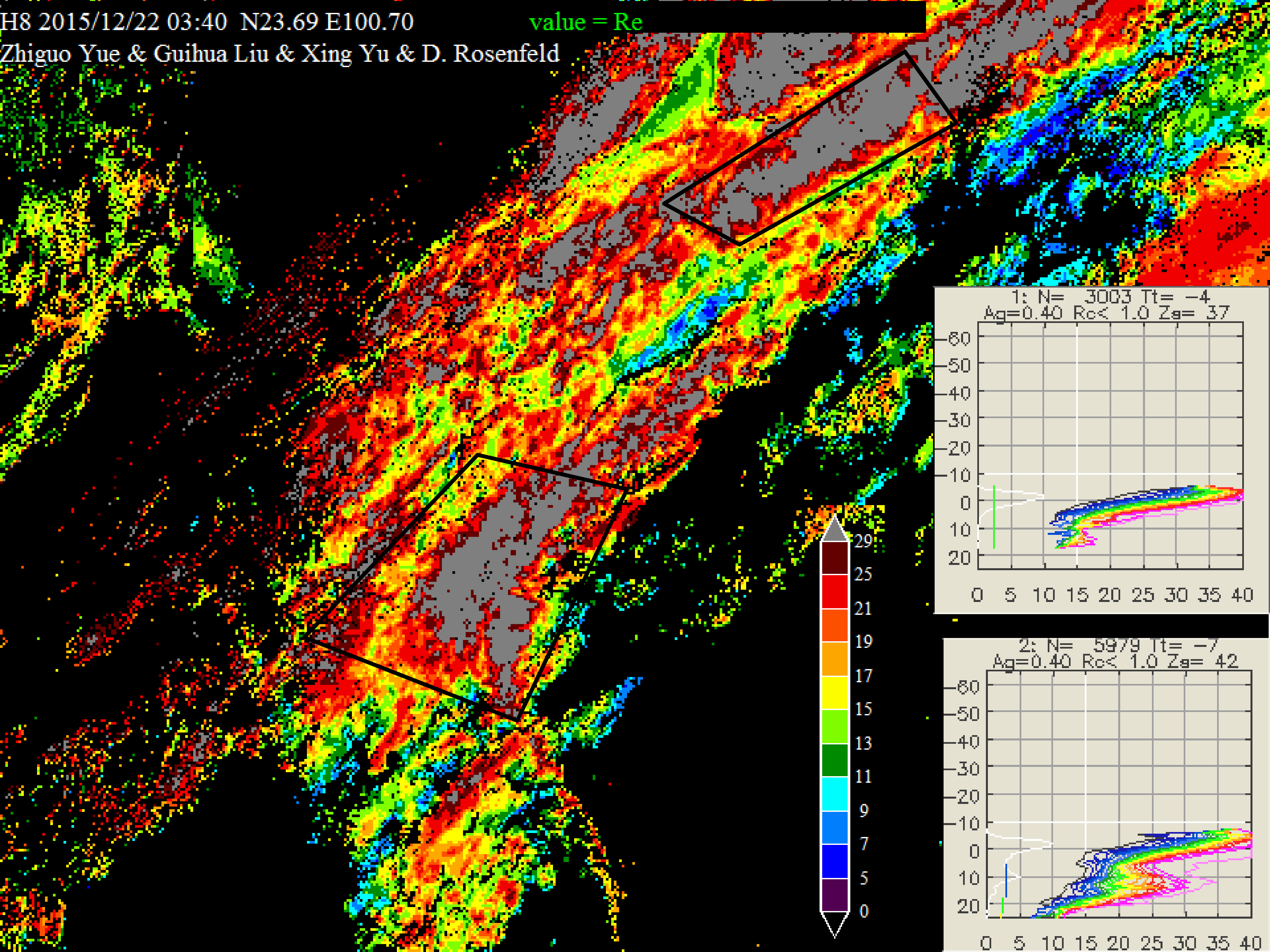
H8 2015/12/22 03:42 N23.69 E100.70
r = refl 1.6
g = refl 2.3
b = refl 0.46
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld
Are the coldest clouds water (yes) or ice (no)?
Red: NIR1.6, Range 0 to 40 %
Green: NIR2.3, Range 0 to 40%
Blue: VIS0.4, Range 0 to 100%

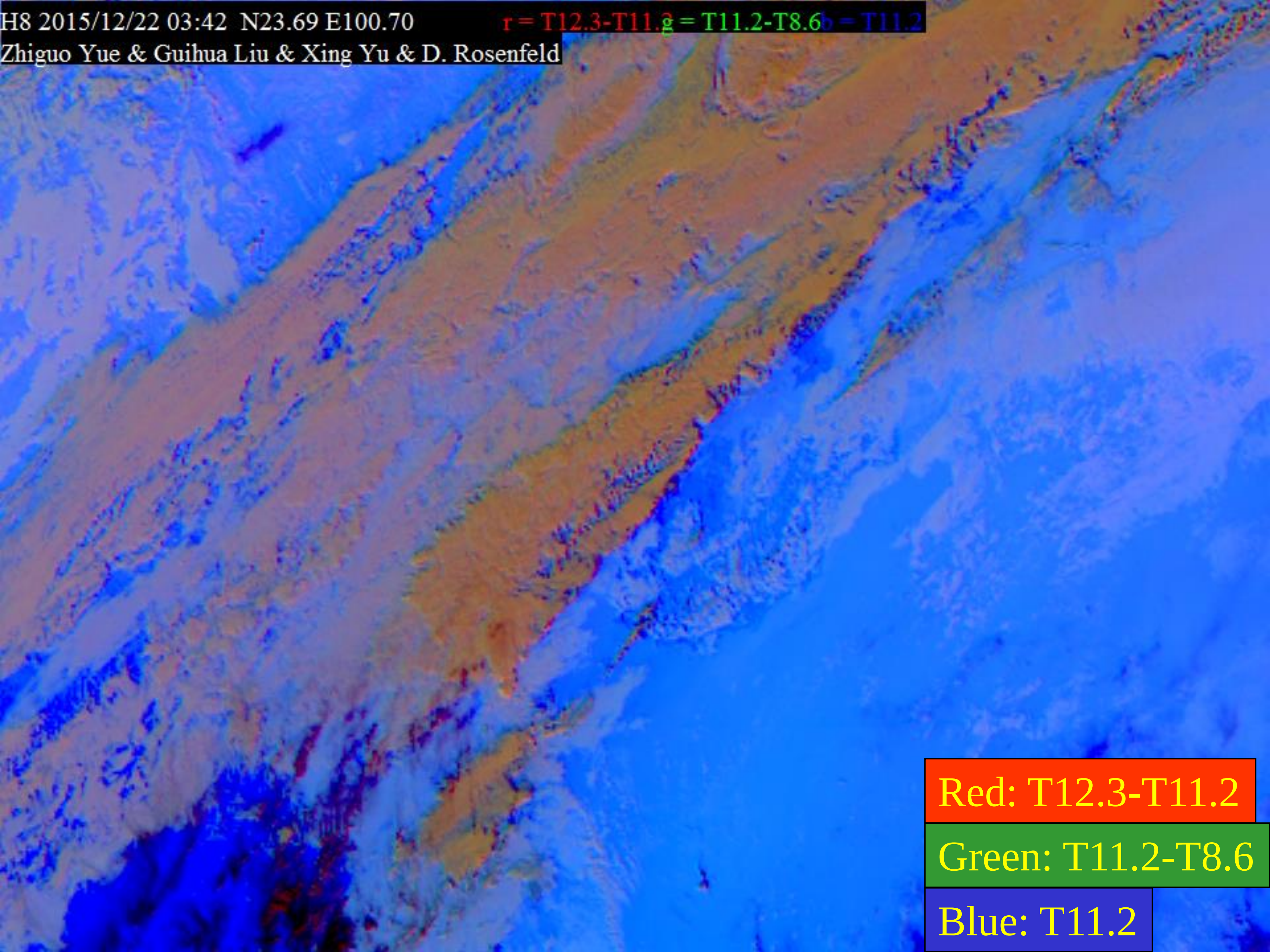


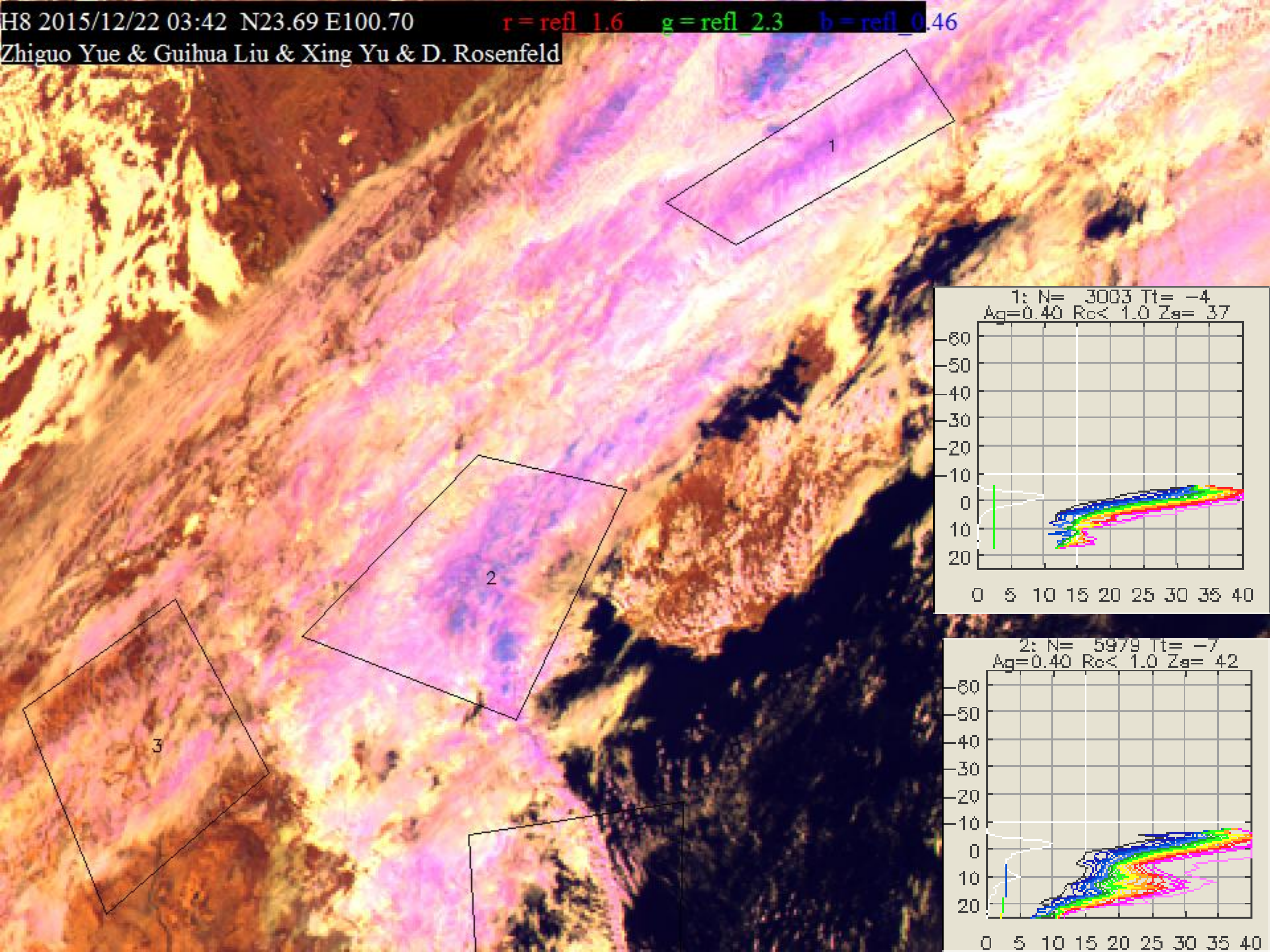
Red: NIR1.6, 0-40 %
Green: NIR2.3, 0-40%
Blue: VIS0.4, 0-100%

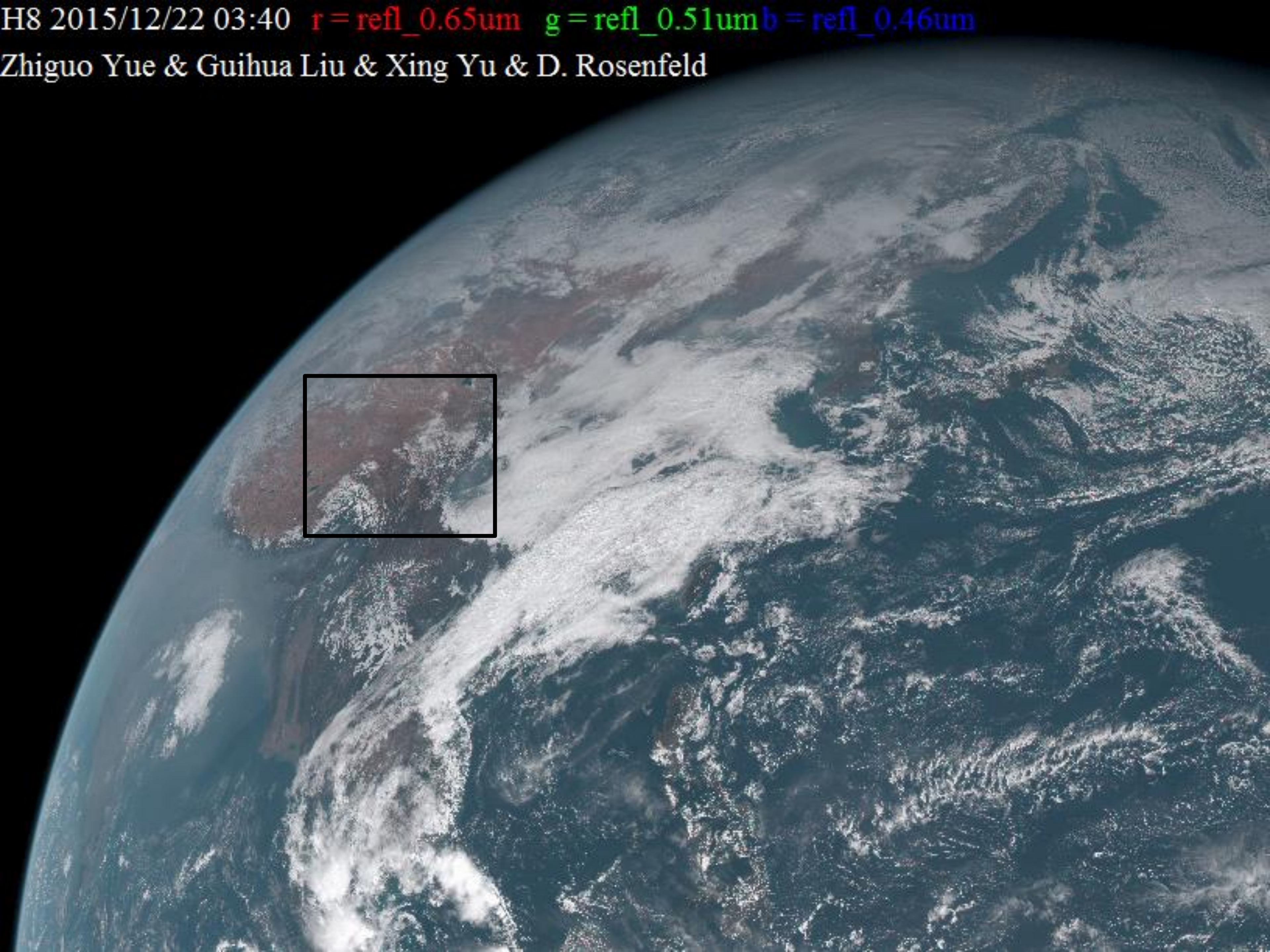


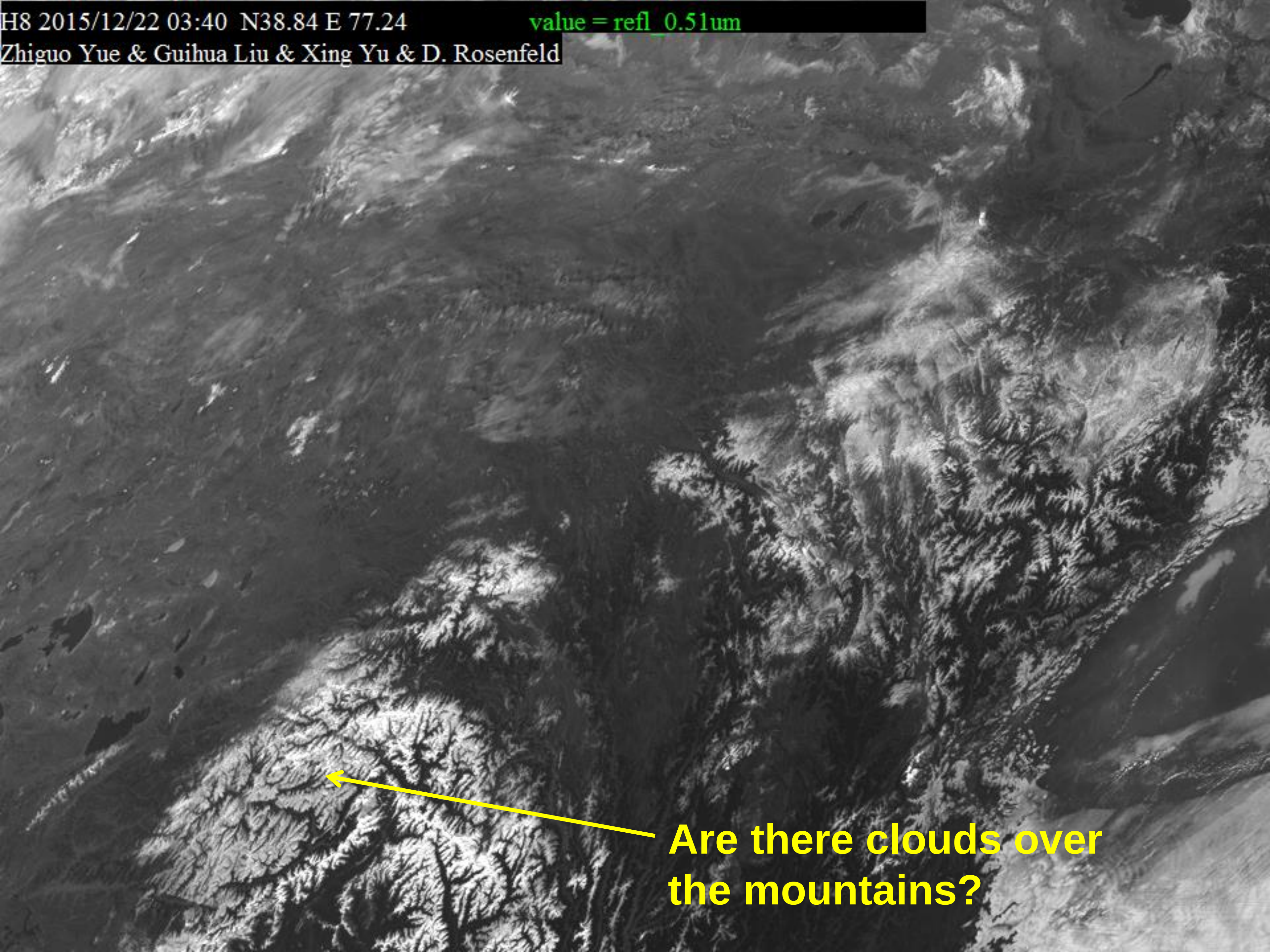
H8 2015/12/22 03:42 N23.69 E100.70
r = refl_1.6
g = refl_2.3
b = refl_0.46
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld
1
2
3
1: N= 3003 Tt= -4
Ag=0.40 Rc< 1.0 Zg= 37
2: N= 5979 Tt= -7
Ag=0.40 Rc< 1.0 Zg= 42

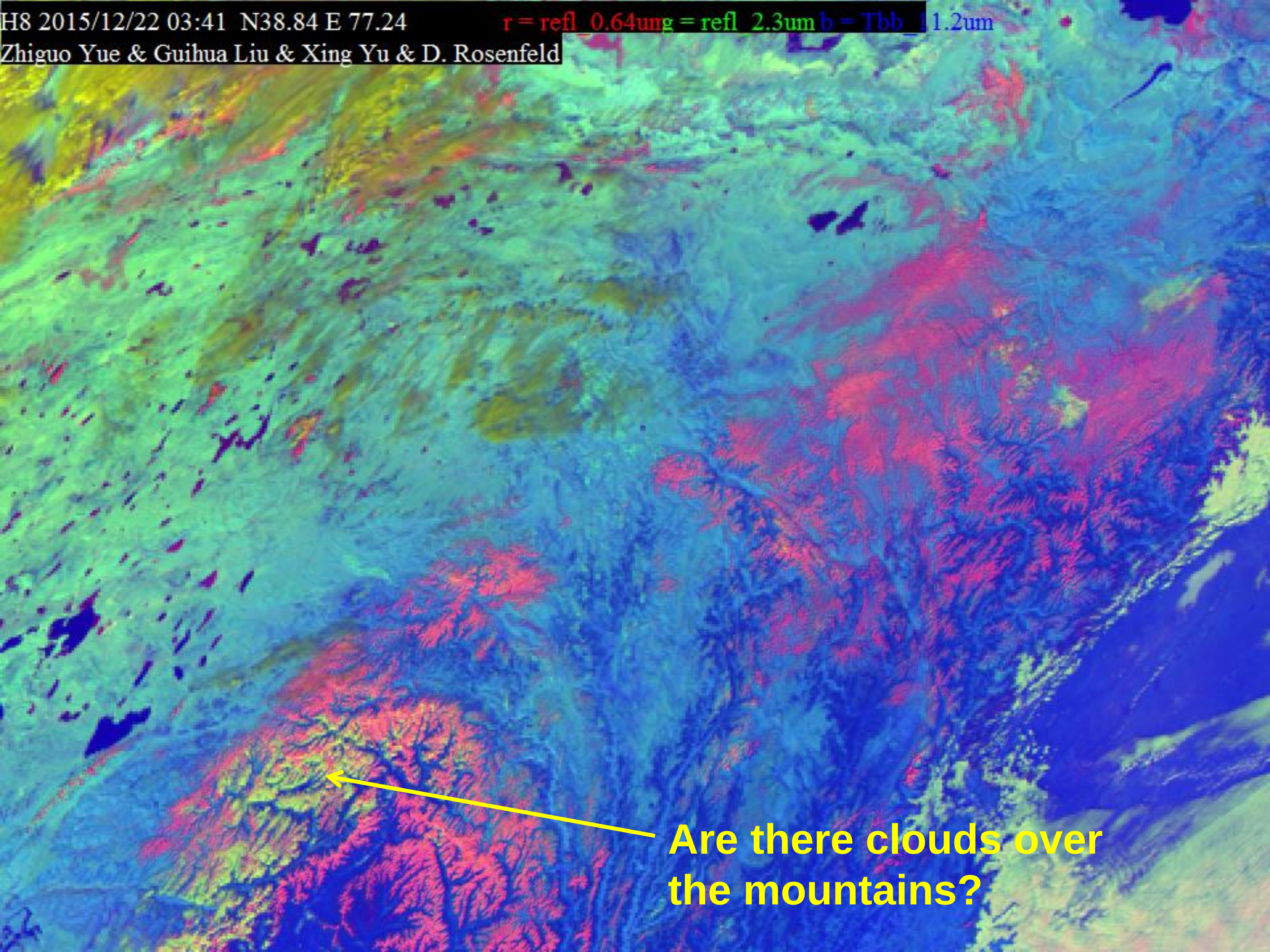

H8 2015/12/22 03:40 N23.69 E100.70
value = Re
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld
1: N= 3003 Tt= -4
Ag=0.40 Rc< 1.0 Zg= 37
-60 -50 -40 -30 -20 -10 0 10 20
0 5 10 15 20 25 30 35 40
2: N= 5979 Tt= -7
Ag=0.40 Rc< 1.0 Zg= 42
-60 -50 -40 -30 -20 -10 0 10 20
0 5 10 15 20 25 30 35 40
29 25 21 19 17 15 13 11 9 7 5 0


H8 2015/12/22 03:42 N23.69 E100.70
r = T12.3-T11.2 g = T11.2-T8.6 b = T11.2
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld
Red: T12.3-T11.2
Green: T11.2-T8.6
Blue: T11.2

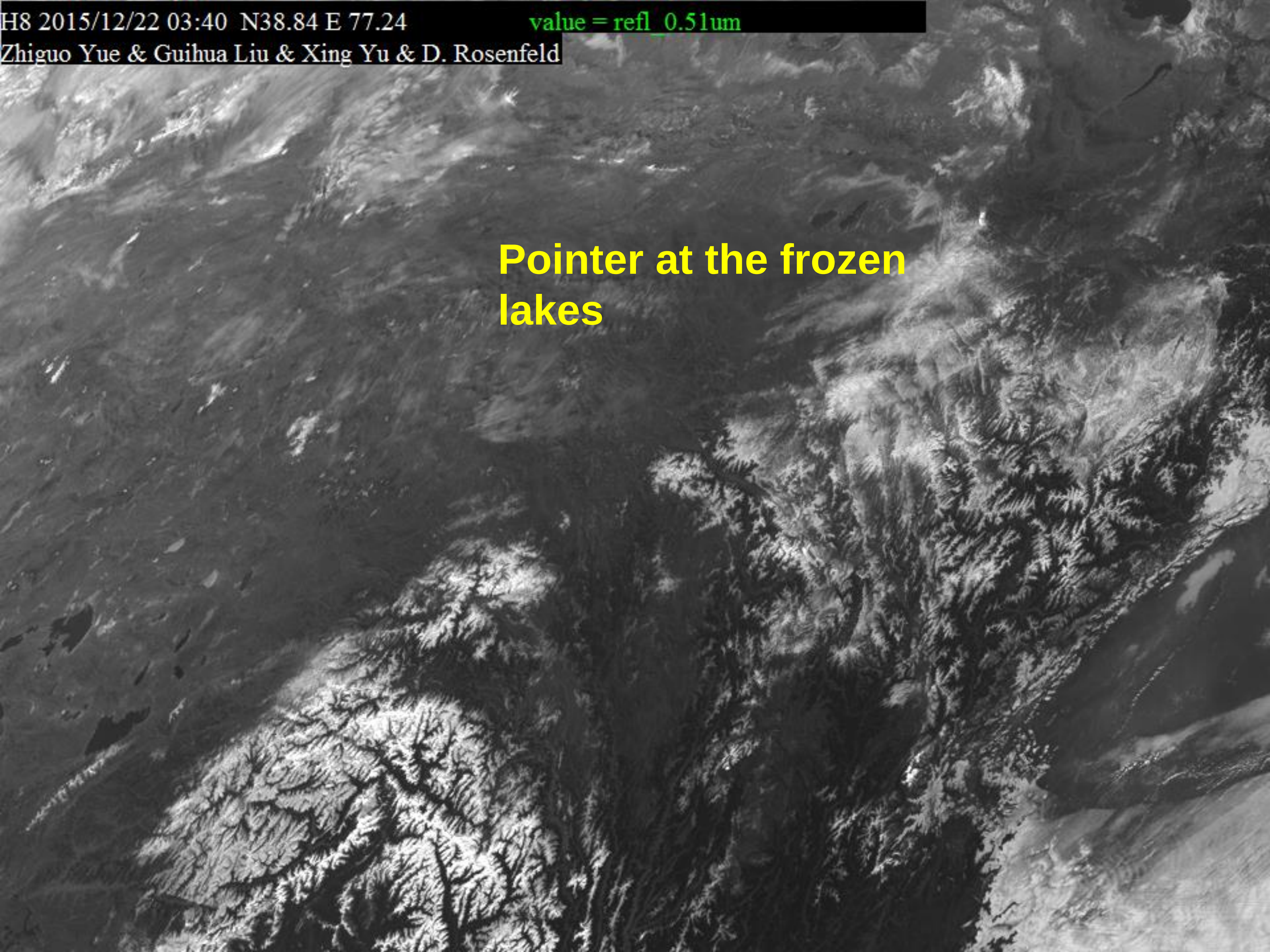

H8 2015/12/22 03:42 N23.69 E100.70
r = refl_1.6 g = refl_2.3 b = refl_0.46
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld
1
2
3
1: N= 3003 Tt= -4
Ag=0.40 Rc< 1.0 Zg= 37
2: N= 5979 Tt= -7
Ag=0.40 Rc< 1.0 Zg= 42
-60
-50
-40
-30
-20
-10
0
10
20
0 5 10 15 20 25 30 35 40

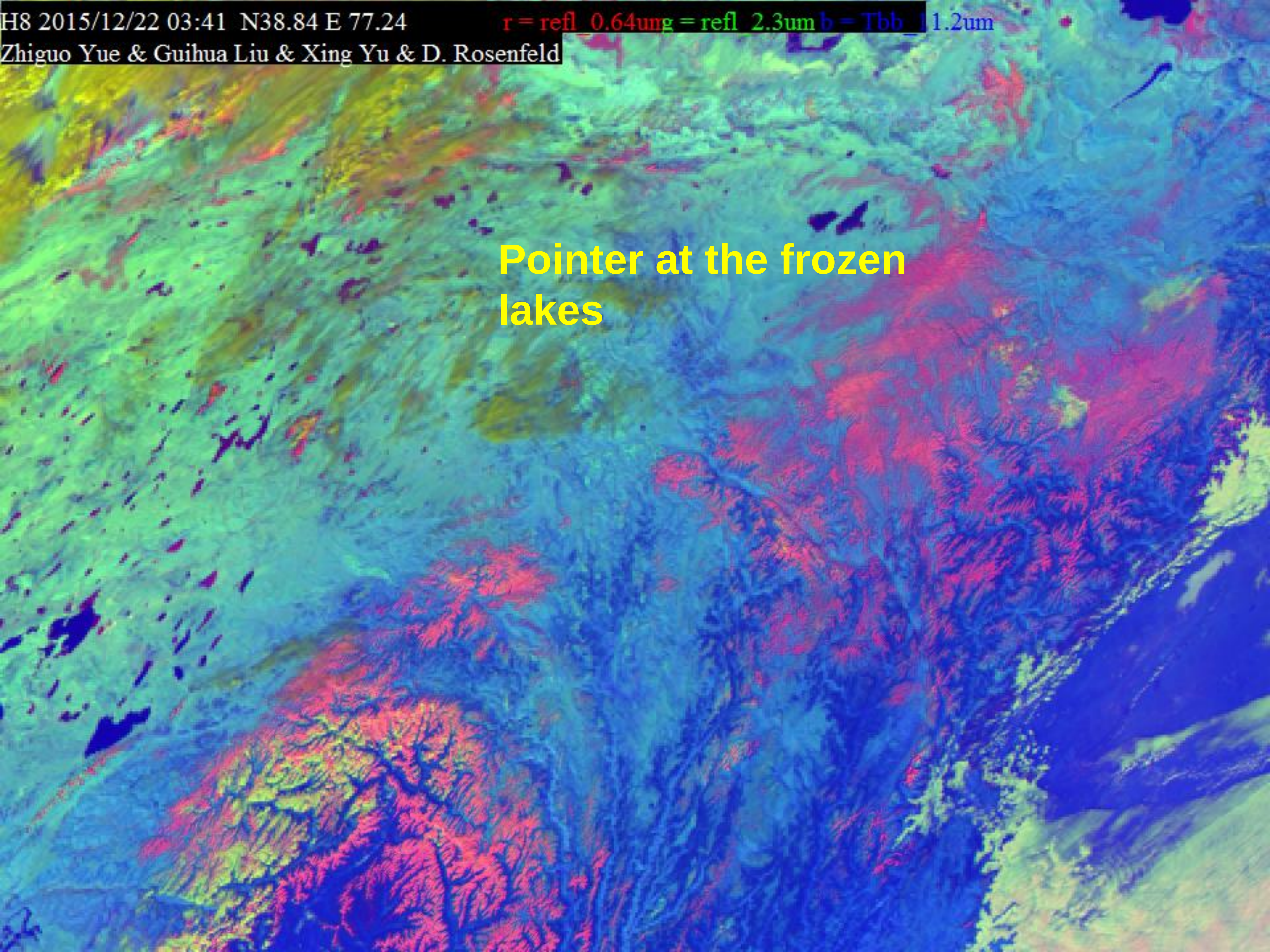

H8 2015/12/22 03:40 r = refl_0.65um g = refl_0.51um b = refl_0.46um
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld

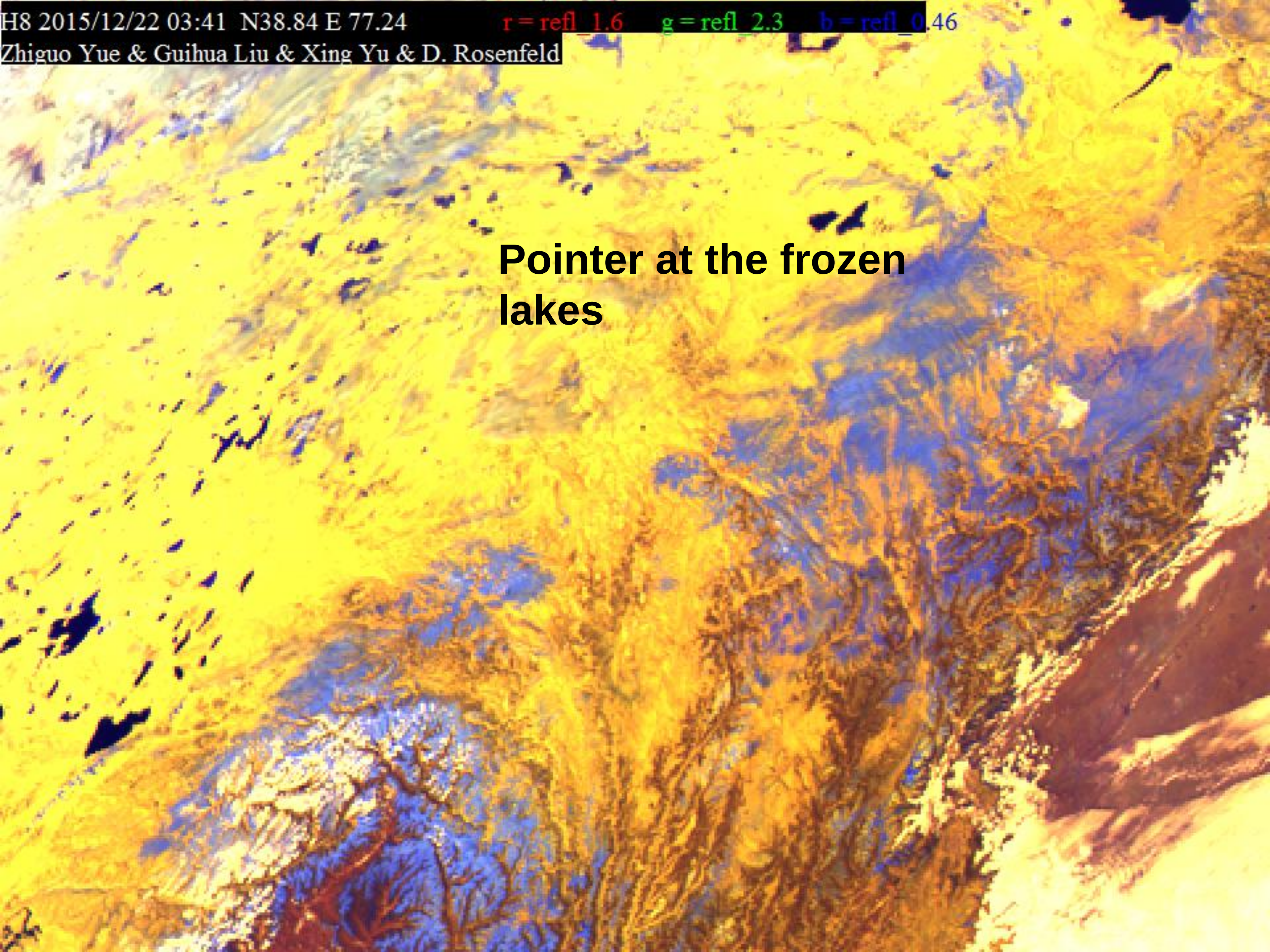

H8 2015/12/22 03:40 N38.84 E 77.24
value = refl_0.51um
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld
Are there clouds over the mountains?

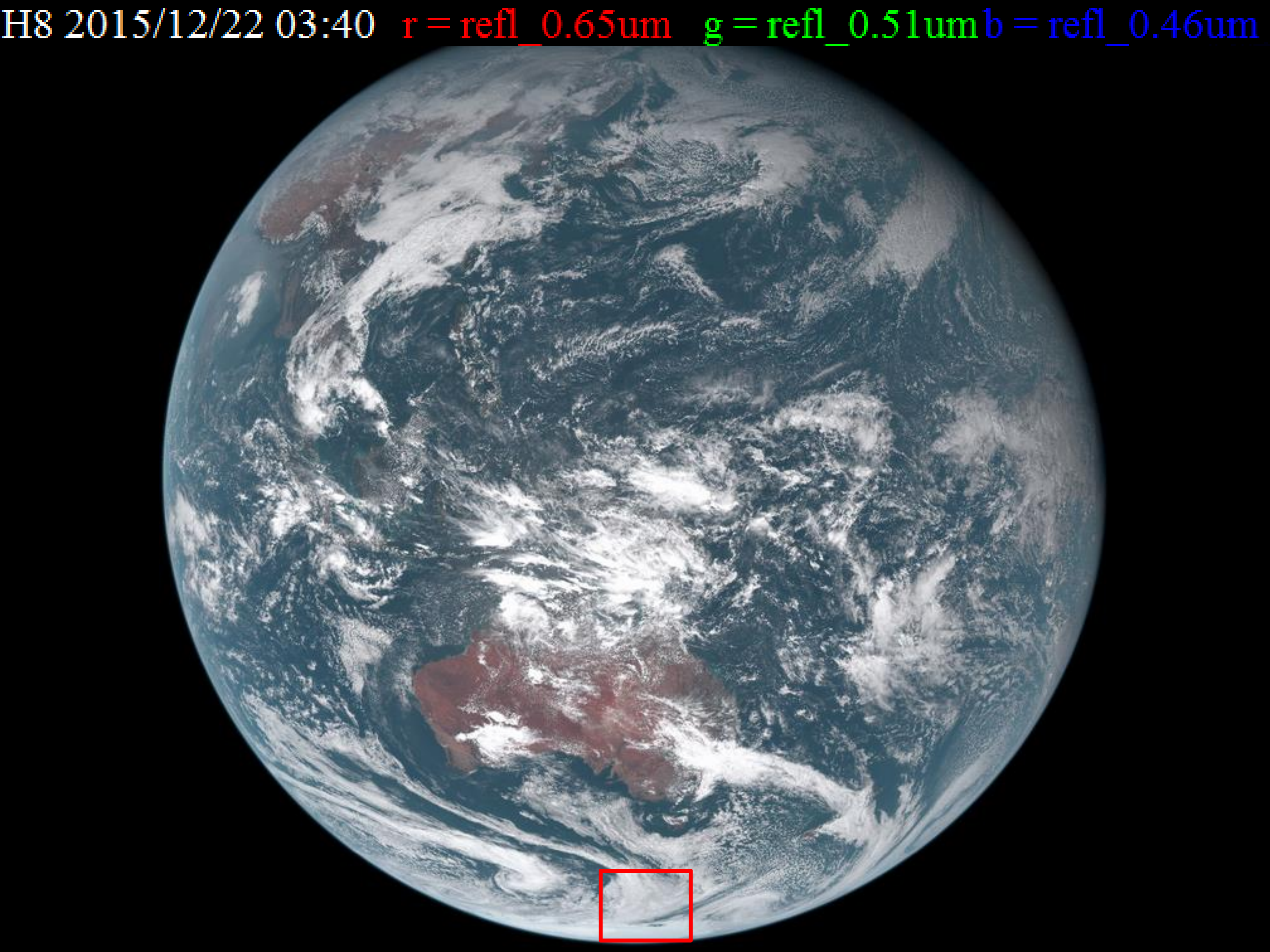

H8 2015/12/22 03:41 N38.84 E 77.24
r = refl_0.64um g = refl_2.3um b = Tbb_11.2um
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld
Are there clouds over the mountains?

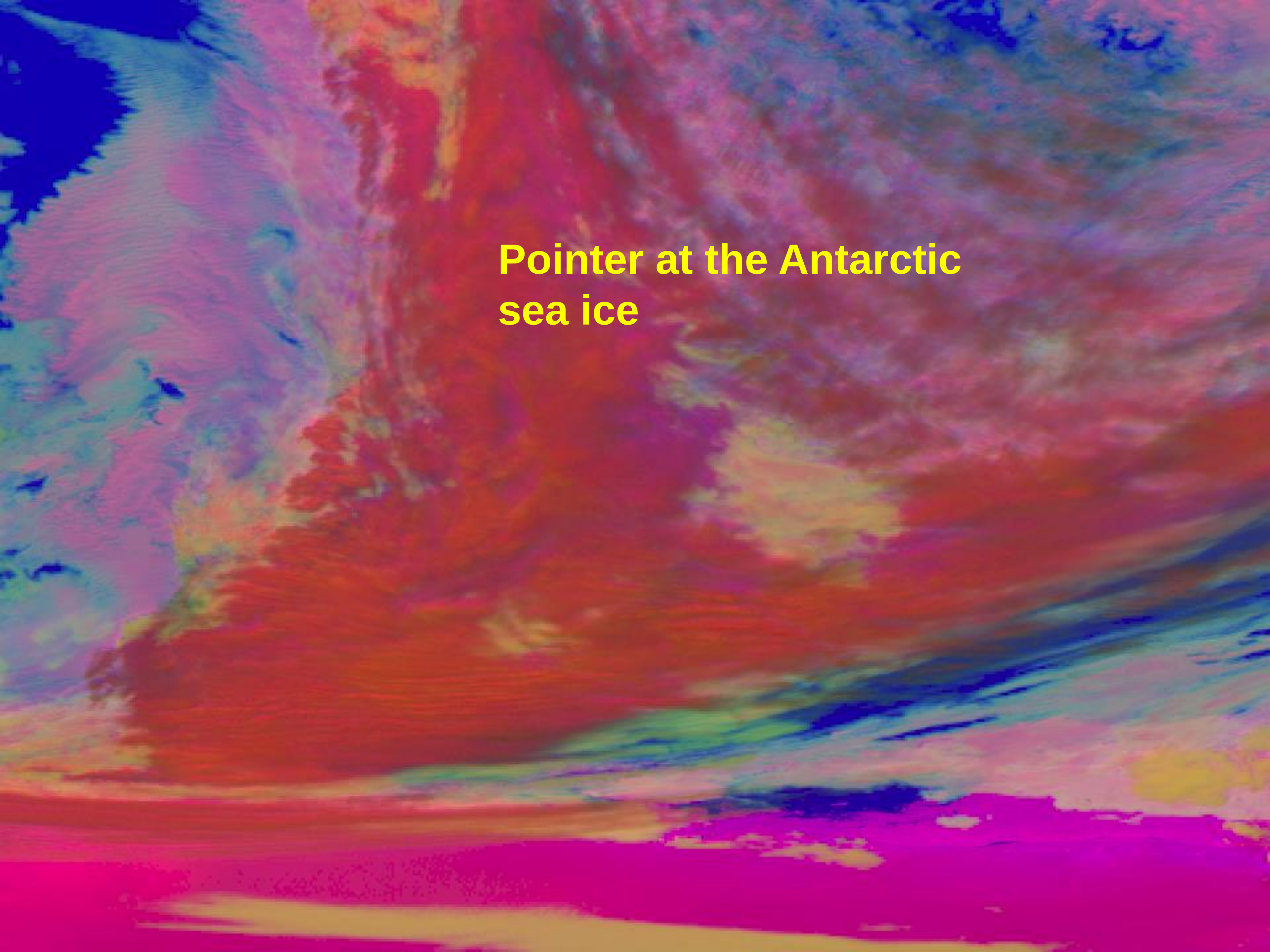

H8 2015/12/22 03:41 N38.84 E 77.24
r = refl_1.6 g = refl_2.3 b = refl_0.46
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld
Are there clouds over the mountains?

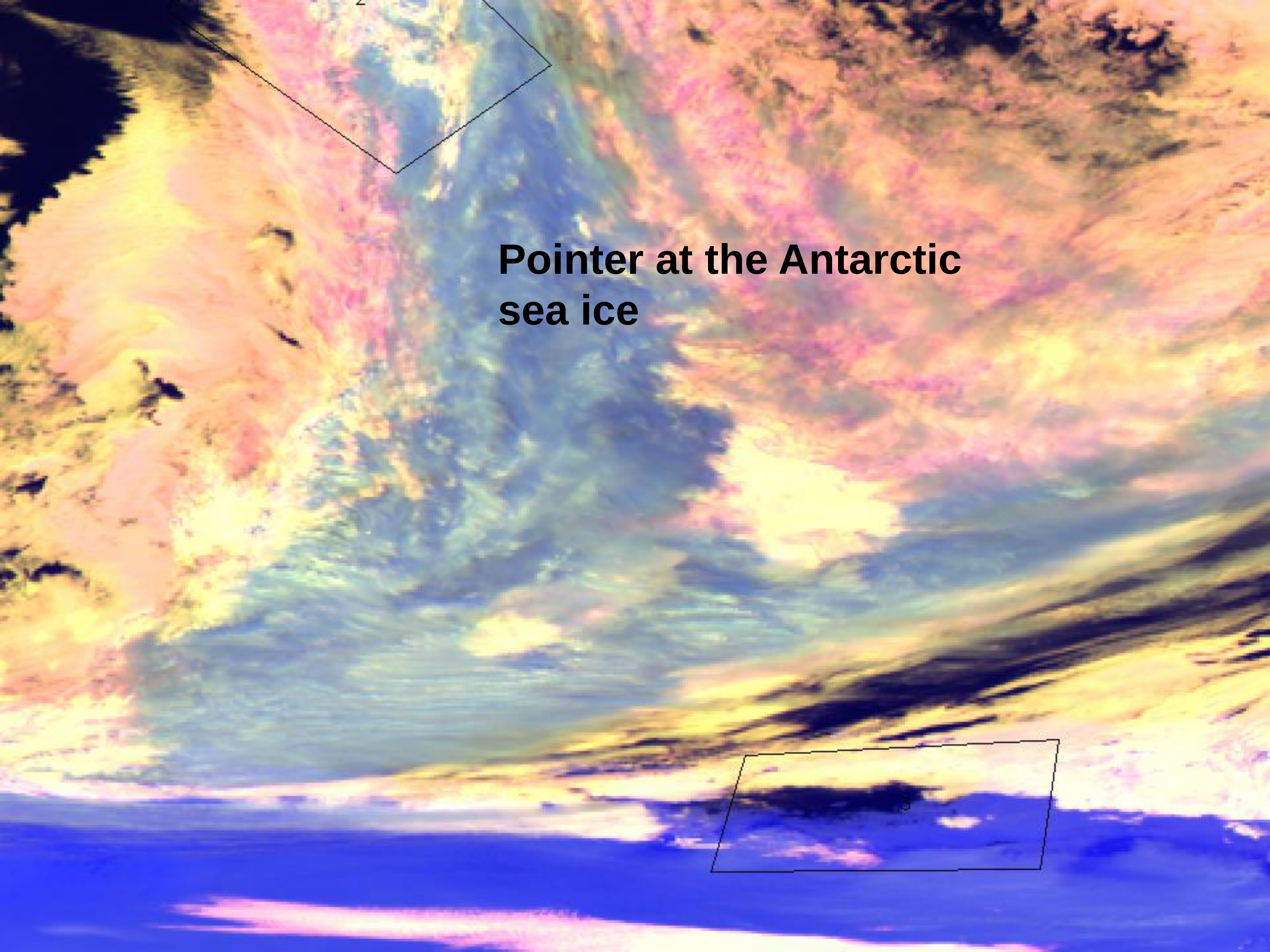

H8 2015/12/22 03:40 N38.84 E 77.24
value = refl_0.51um
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld
Pointer at the frozen lakes


H8 2015/12/22 03:41 N38.84 E 77.24
r = refl_0.64um g = refl_2.3um b = Tbb_11.2um
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld
Pointer at the frozen lakes


H8 2015/12/22 03:41 N38.84 E 77.24
r = refl_1.6
g = refl_2.3
b = refl_0.46
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld
Pointer at the frozen lakes


H8 2015/12/22 03:40
r = refl_0.65um
g = refl_0.51um
b = refl_0.46um

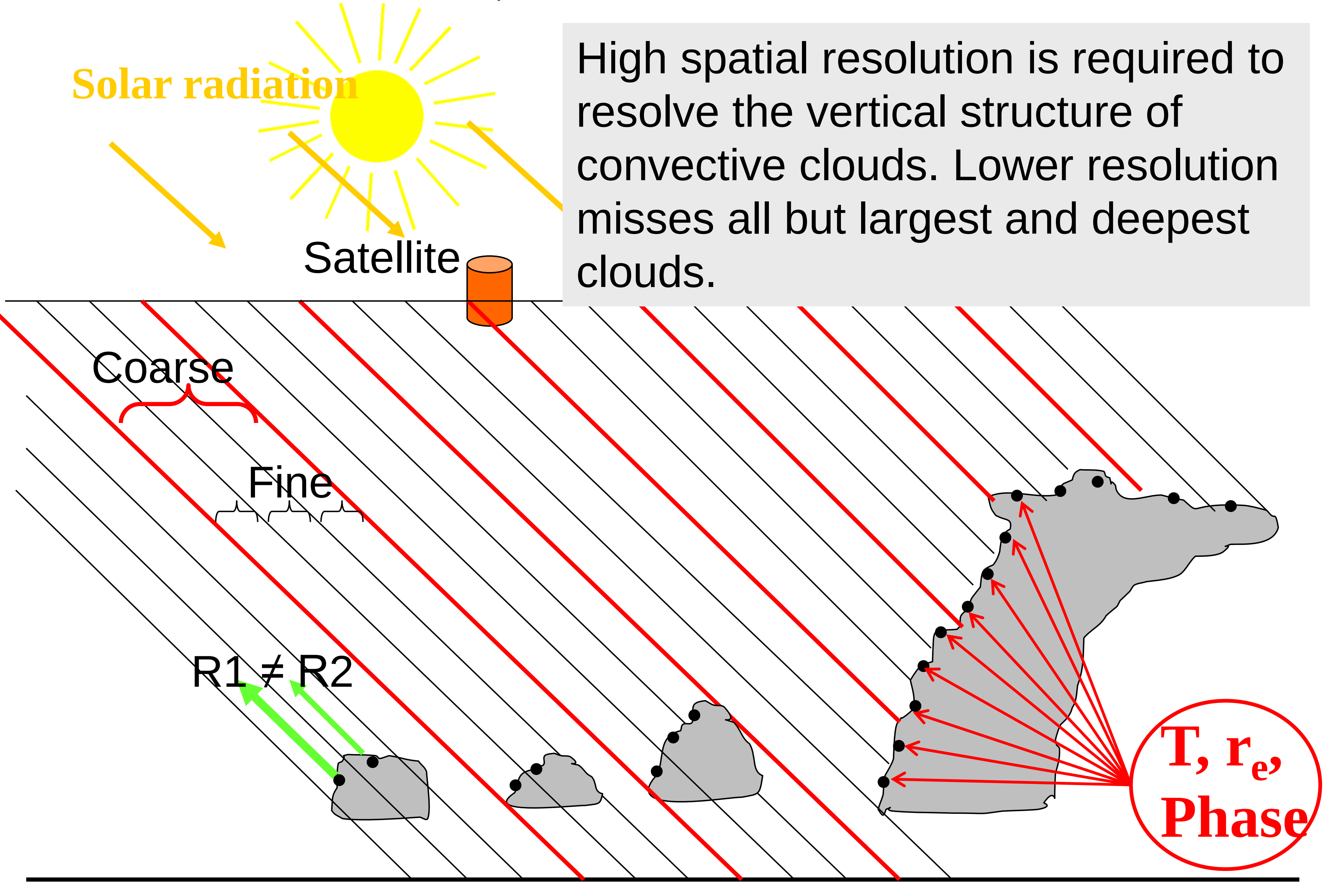

Pointer at the Antarctic
sea ice


Pointer at the Antarctic sea ice

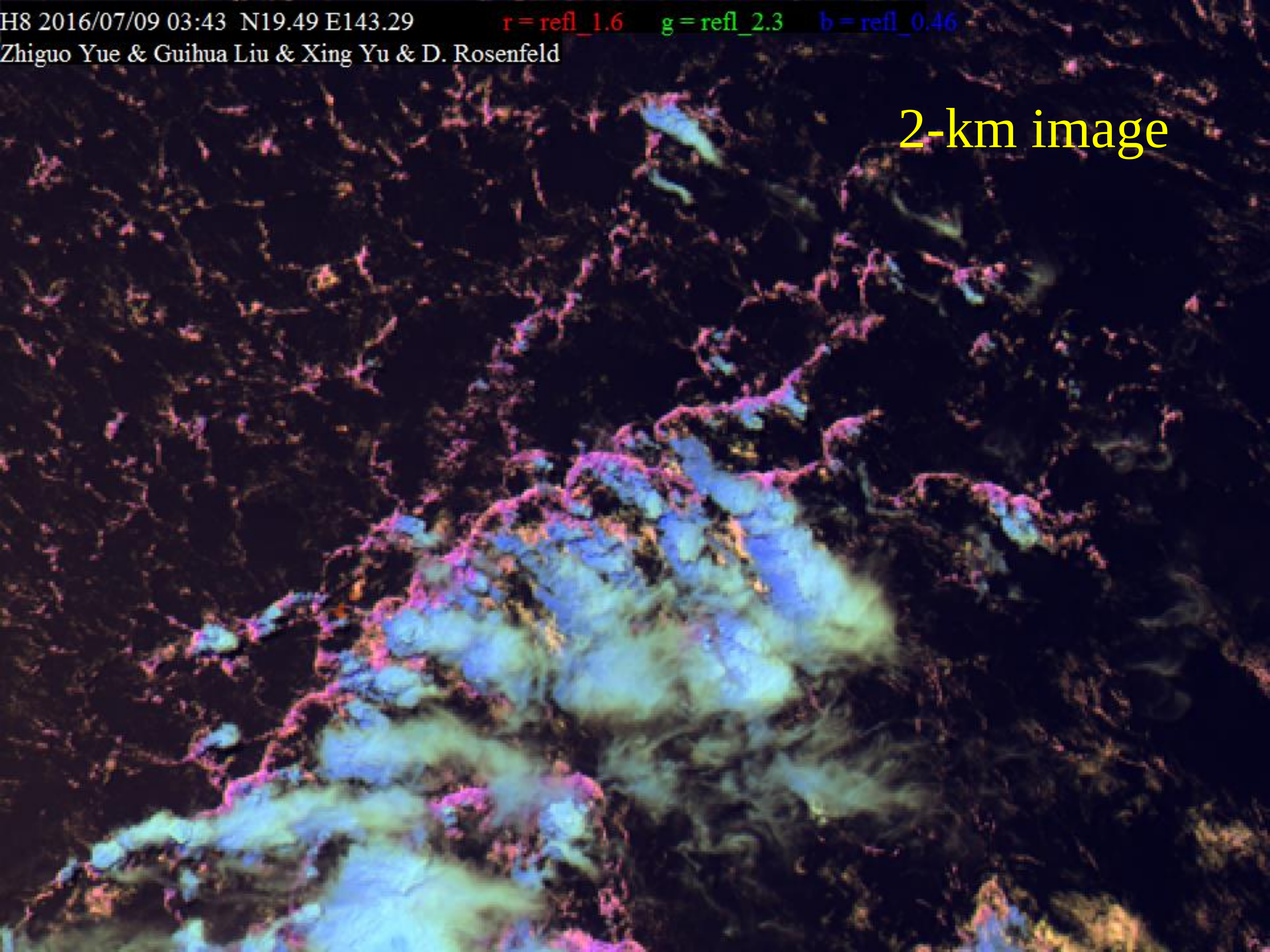
CHANNEL	CENTRE WAVELENGTH	SPECTRAL WIDTH	SPATIAL SAMPLING DISTANCE (SSD)
VIS 0.4	0.444 µm	0.060 µm	1.0 km
VIS 0.5	0.510 µm	0.040 µm	1.0 km
VIS 0.6	0.640 µm	0.050 µm	1.0 km; 0.5 km*
VIS 0.8	0.865 µm	0.050 µm	1.0 km
VIS 0.9	0.914 µm	0.020 µm	1.0 km
NIR 1.3	1.380 µm	0.030 µm	1.0 km
NIR 1.6	1.610 µm	0.050 µm	1.0 km
NIR 2.2	2.250 µm	0.050 µm	1.0 km; 0.5 km*
IR 3.8 (TIR)	3.800 µm	0.400 µm	2.0 km; 1.0 km*
WV 6.3	6.300 µm	1.000 µm	2.0 km
WV 7.3	7.350 µm	0.500 µm	2.0 km
IR 8.7 (TIR)	8.700 µm	0.400 µm	2.0 km
IR 9.7 (O_3)	9.660 µm	0.300 µm	2.0 km
IR 10.5 (TIR)	10.500 µm	0.700 µm	2.0 km; 1.0 km*
IR 12.3 (TIR)	12.300 µm	0.500 µm	2.0 km
IR 13.3 (CO_2)	13.300 µm	0.600 µm	2.0 km

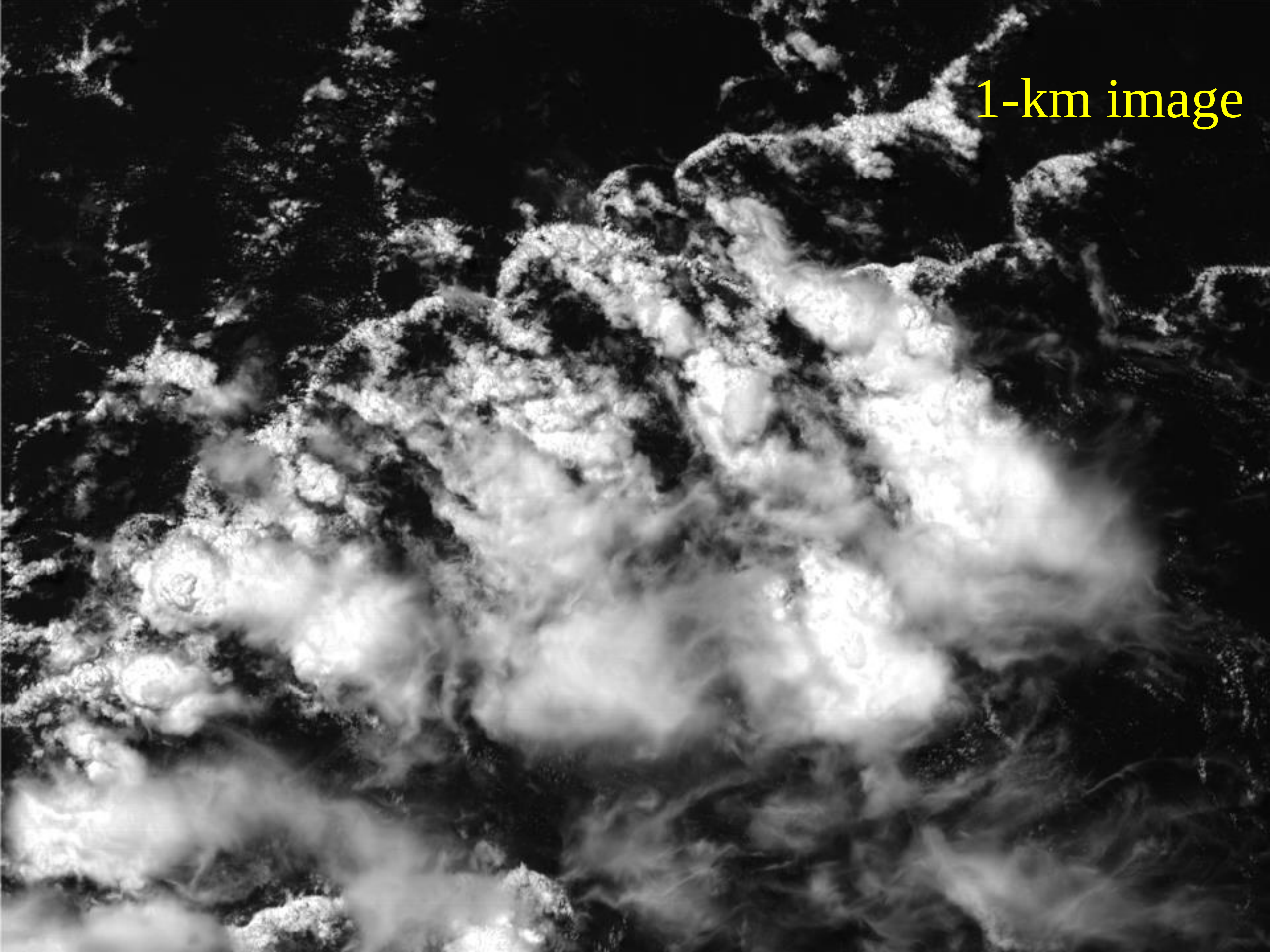
Note: *The channels VIS 0.6, NIR 2.2, IR 3.8 and IR 10.5 are delivered in both FDS and RRS sampling configurations, the latter is indicated by * in the table.*

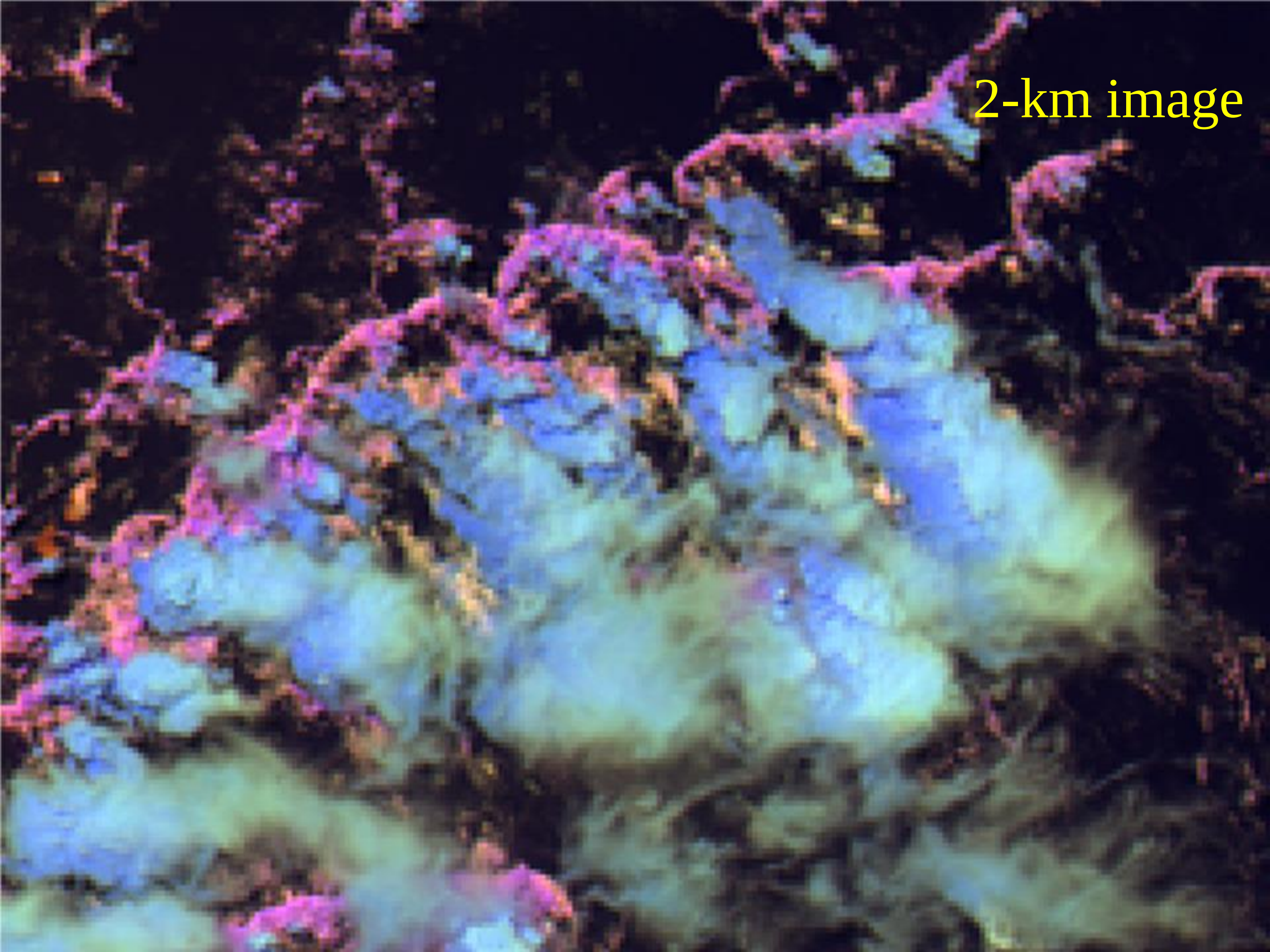
High spatial resolution is required to resolve the vertical structure of convective clouds. Lower resolution misses all but largest and deepest clouds.



Measurement concept for T-r_e based CCN retrievals


H8 2016/07/09 03:43 N19.49 E143.29
r = refl_1.6
g = refl_2.3
b = refl_0.46
Zhiguo Yue & Guihua Liu & Xing Yu & D. Rosenfeld
2-km image

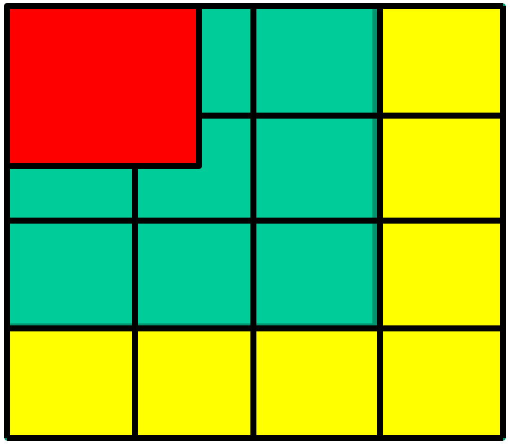

1-km image

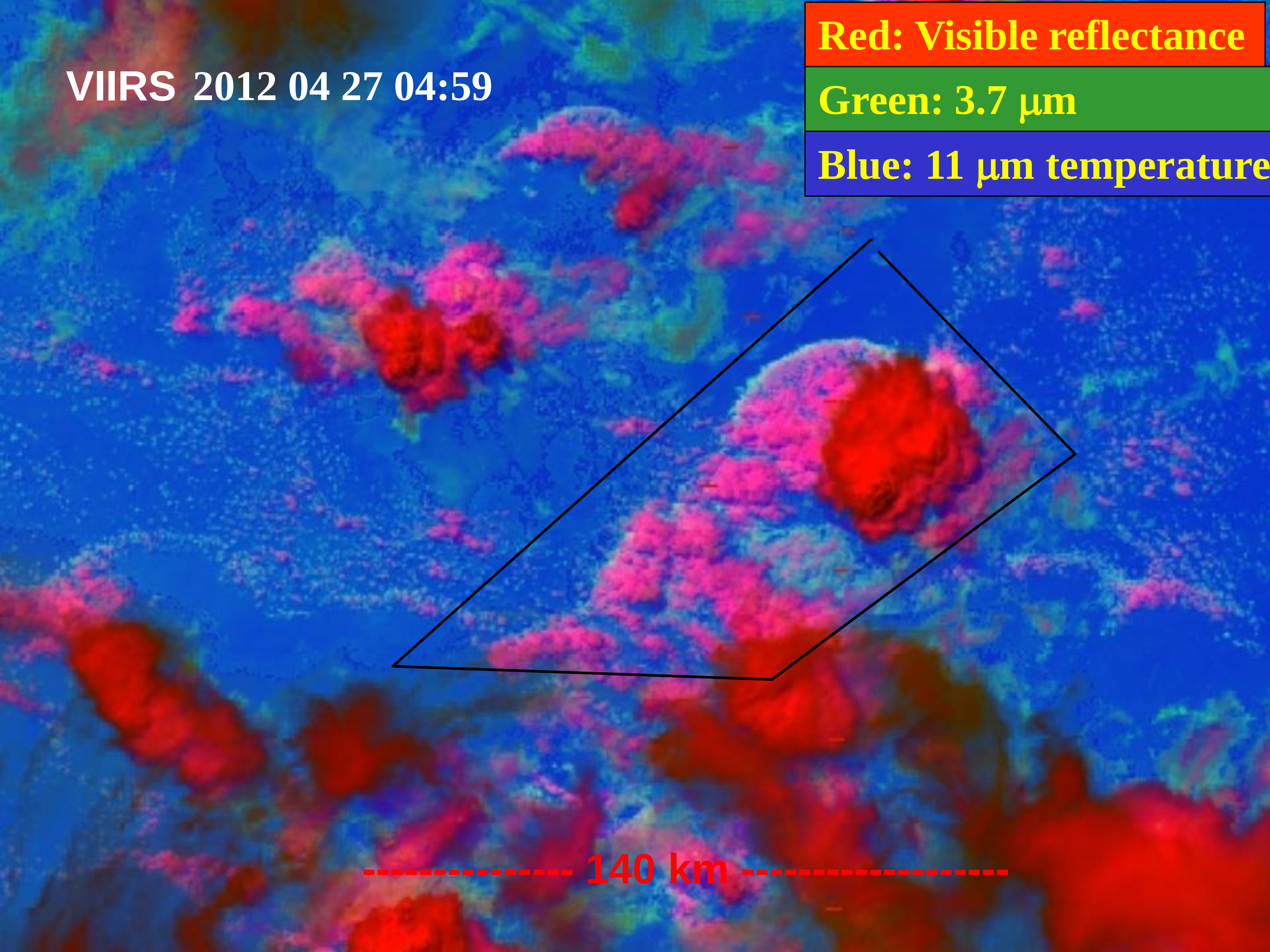

2-km image

MODIS microphysical resolution: 1000 m

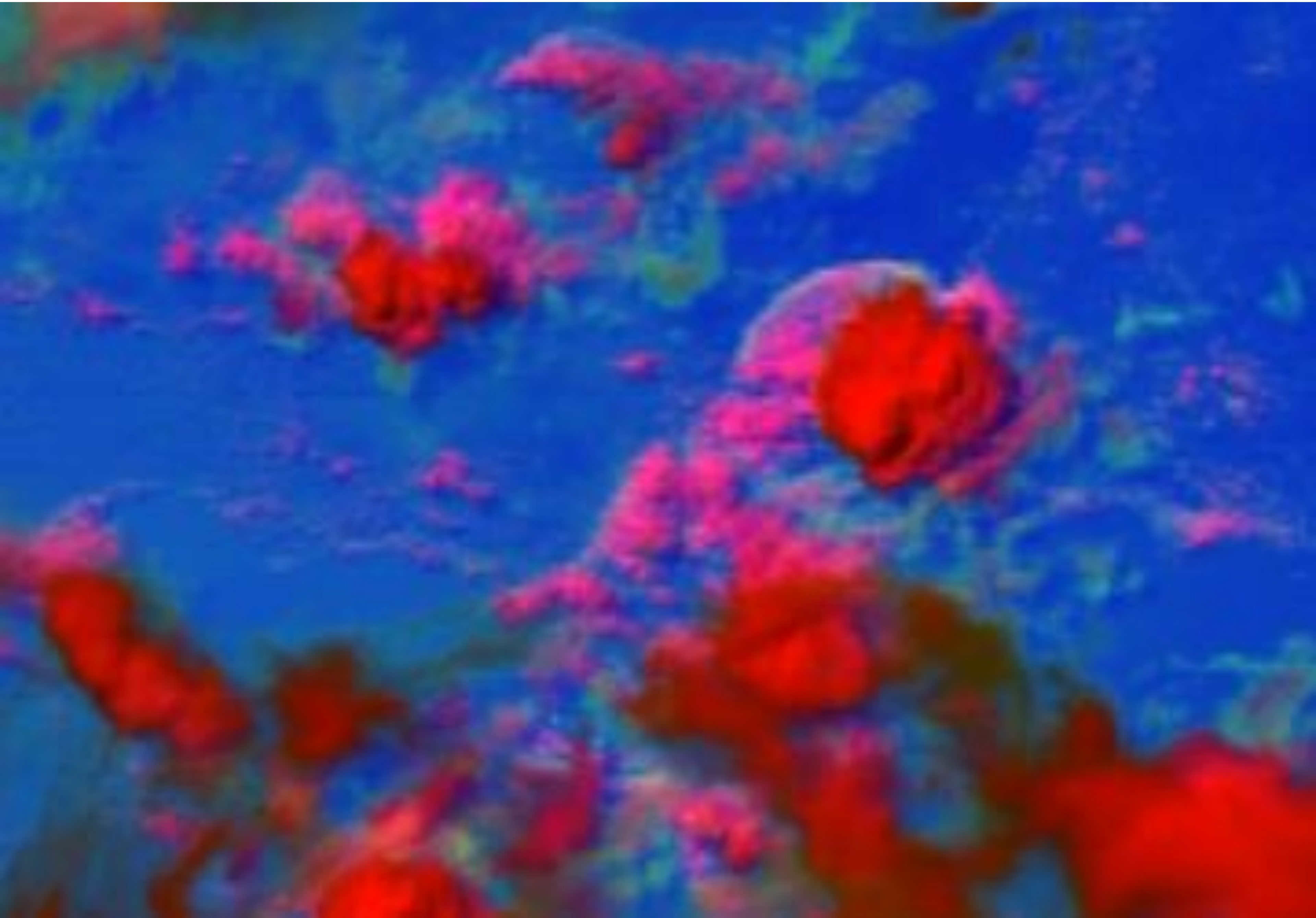
NPP/VIIRS products resolution: 750 m

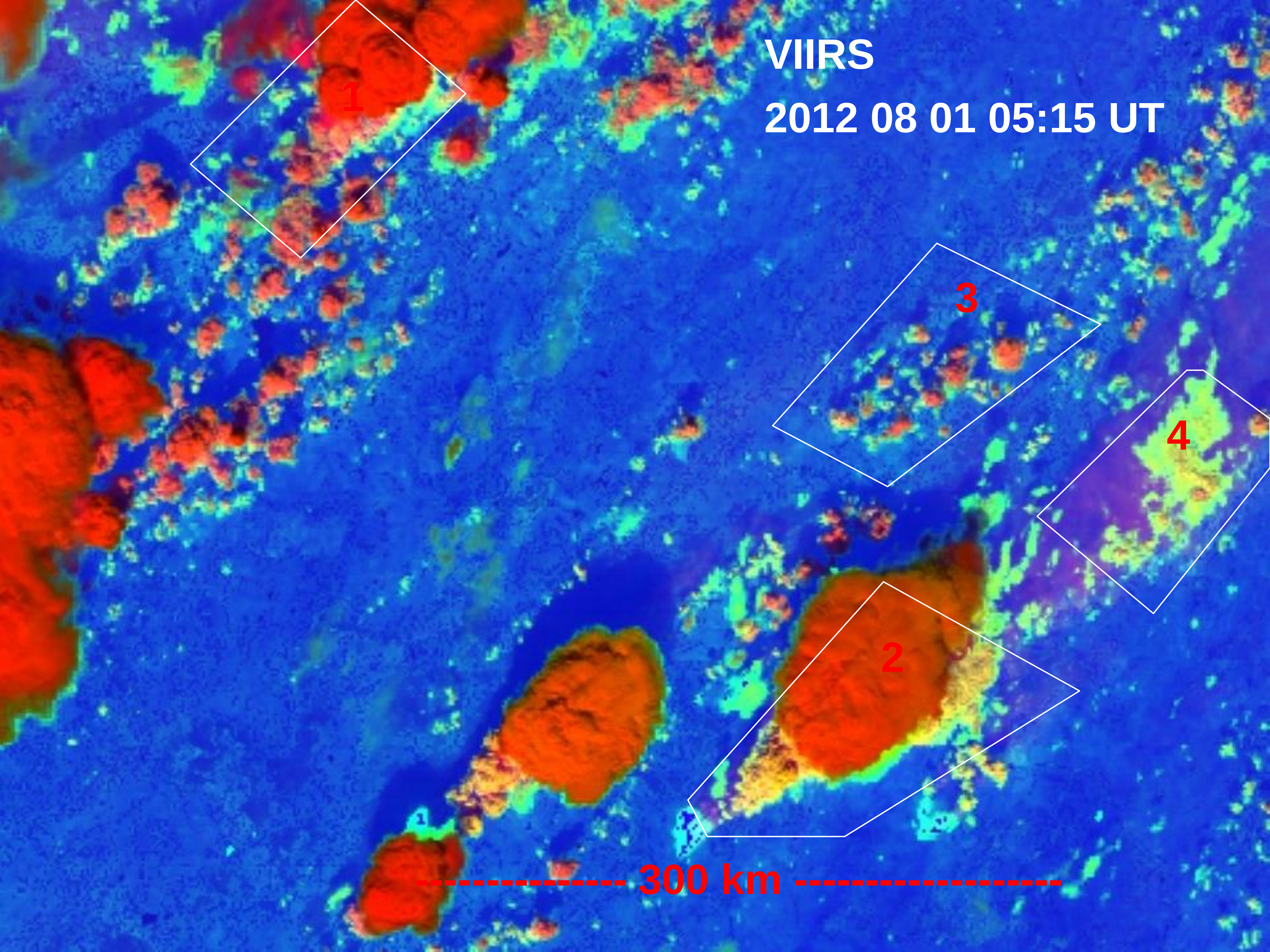
NPP/VIIRS Imager resolution: 375 m

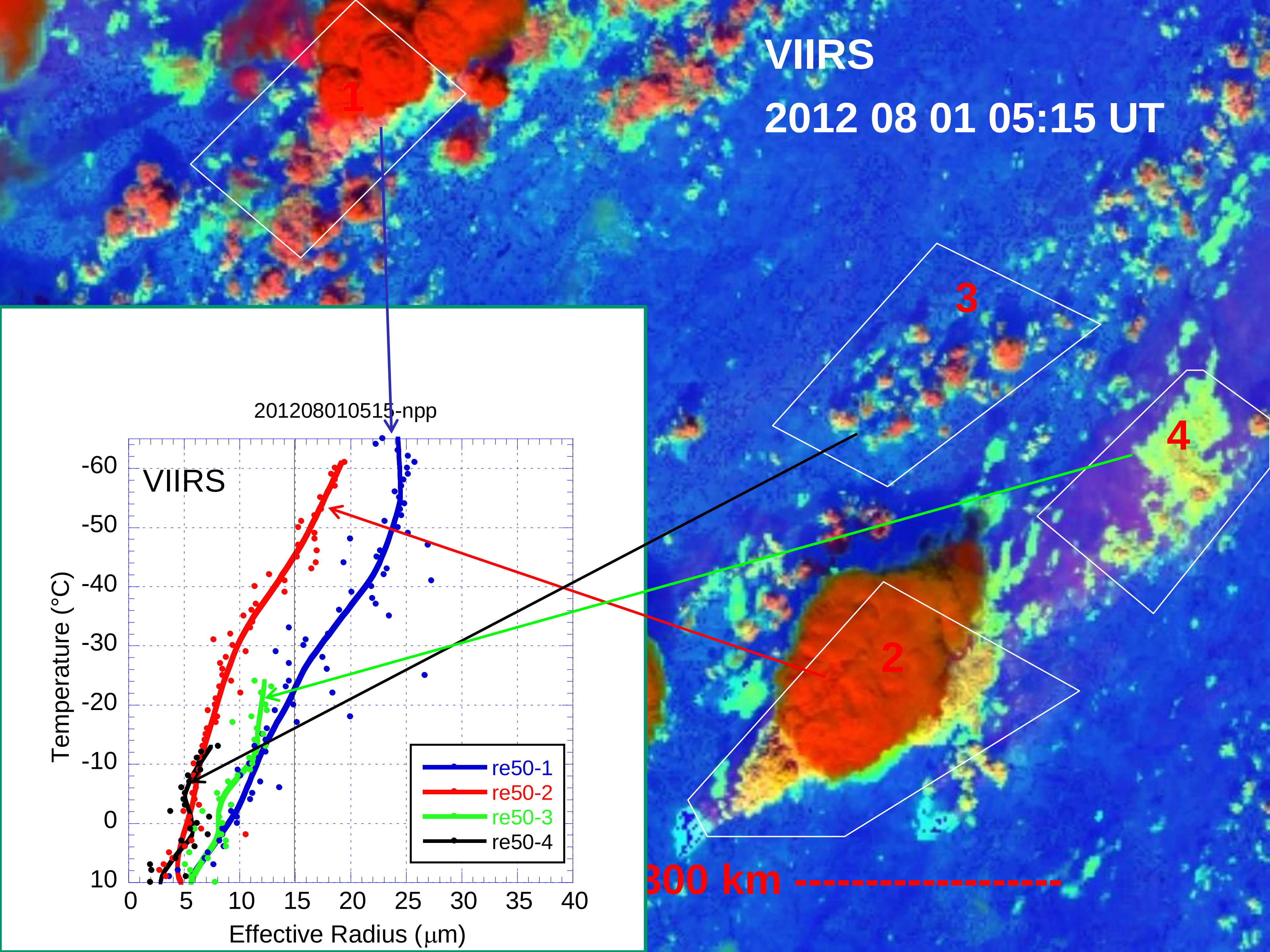


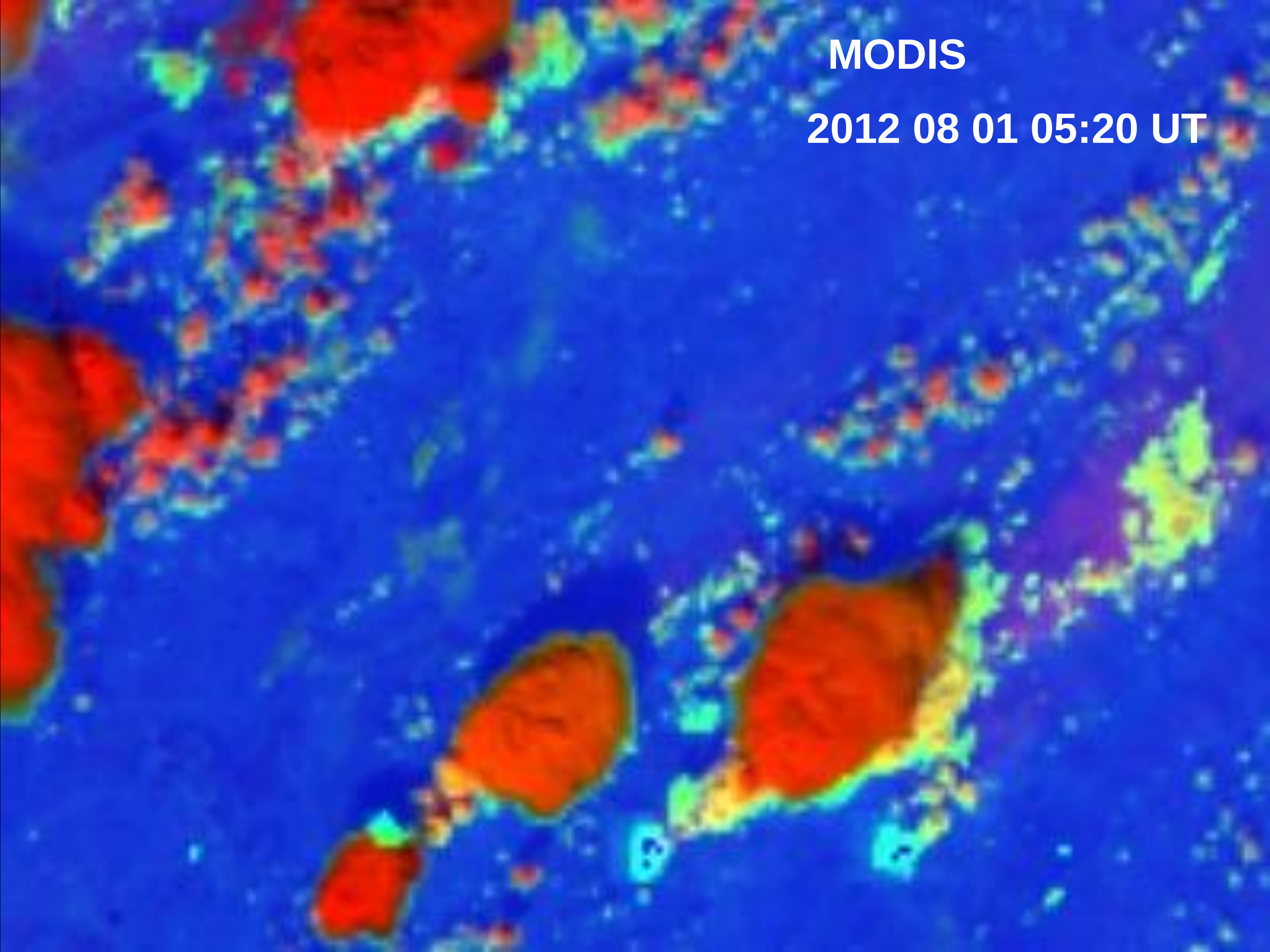

VIIRS 2012 04 27 04:59
Red: Visible reflectance
Green: 3.7 µm
Blue: 11 µm temperature
140 km

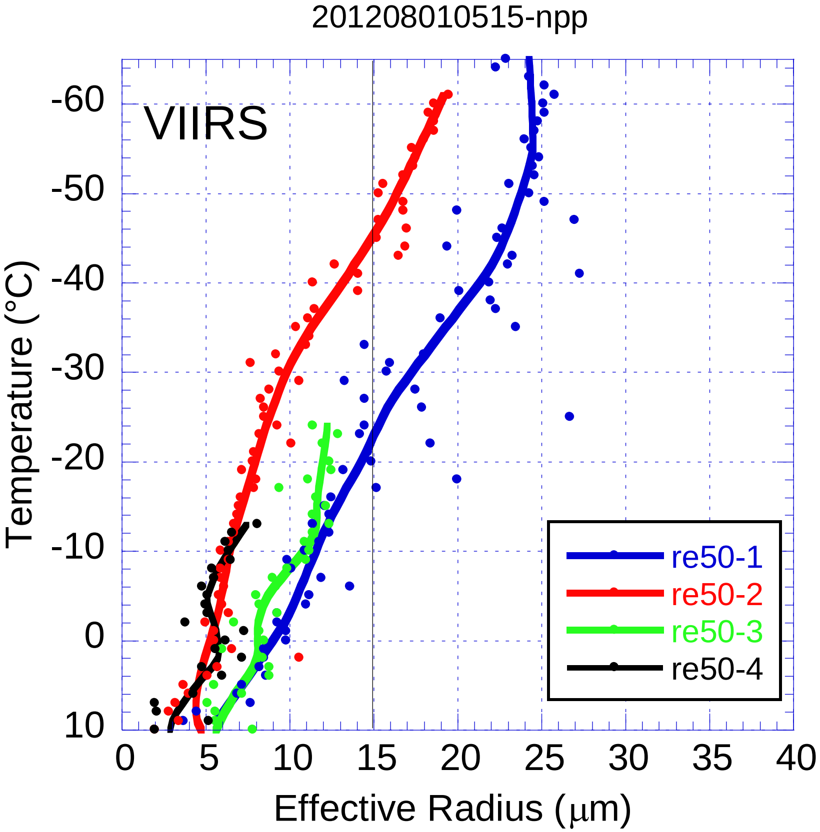
MODIS 2012 04 27 05:00



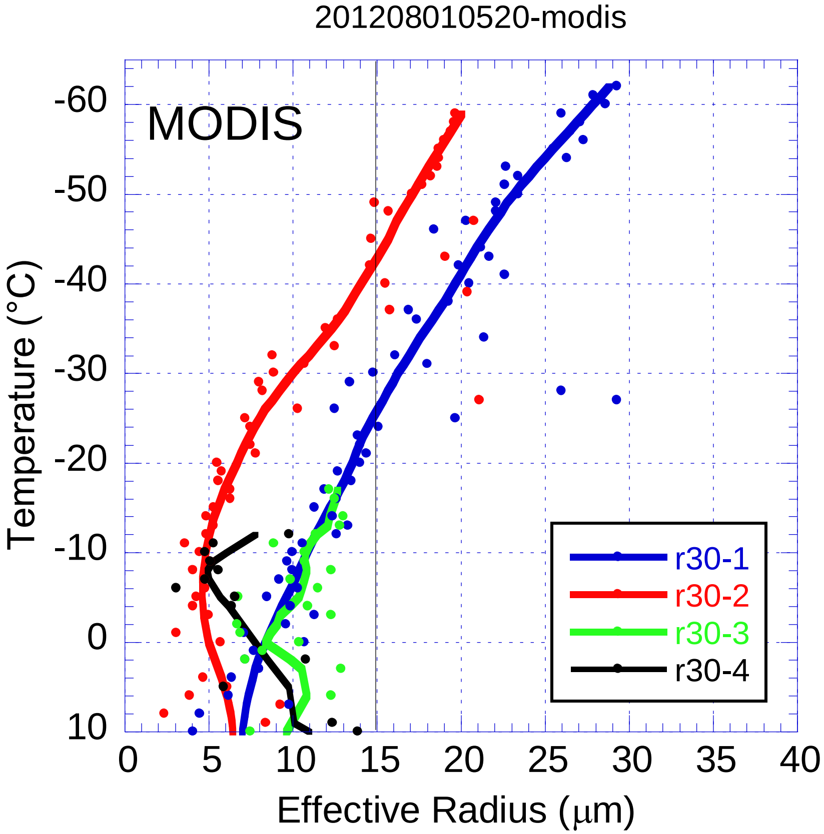

VIIRS
2012 08 01 05:15 UT
1
2
3
4
300 km


VIIRS
2012 08 01 05:15 UT
1
2
3
4
300 km
201208010515-npp
VIIRS
Temperature (°C)
Effective Radius (μm)
re50-1
re50-2
re50-3
re50-4


MODIS
2012 08 01 05:20 UT



201208010515-npp
VIIRS
-60
-50
-40
-30
-20
-10
0
10
Temperature (°C)
0
5
10
15
20
25
30
35
40
Effective Radius (μm)
re50-1
re50-2
re50-3
re50-4



201208010520-modis
MODIS
-60
-50
-40
-30
-20
-10
0
10
Temperature (°C)
0
5
10
15
20
25
30
35
40
Effective Radius (μm)
r30-1
r30-2
r30-3
r30-4

Summary

Until now ice cloud was differentiated from supercooled water cloud mainly based on assumption that ice crystals are typically much larger that cloud drops.

However, supercooled clouds can have very large drops Using a combination that cause ambiguity with ice.

Because ice absorbs more strongly at 1.6 μm while water absorbs more strongly at 2.3 μm, the combination these channels allows an unambiguous separation between water and ice clouds.