

**APPLICATIONS OF
METEOSAT SECOND GENERATION (MSG)
FOR INSIGHTS INTO**

CONVECTIVE CLOUDS



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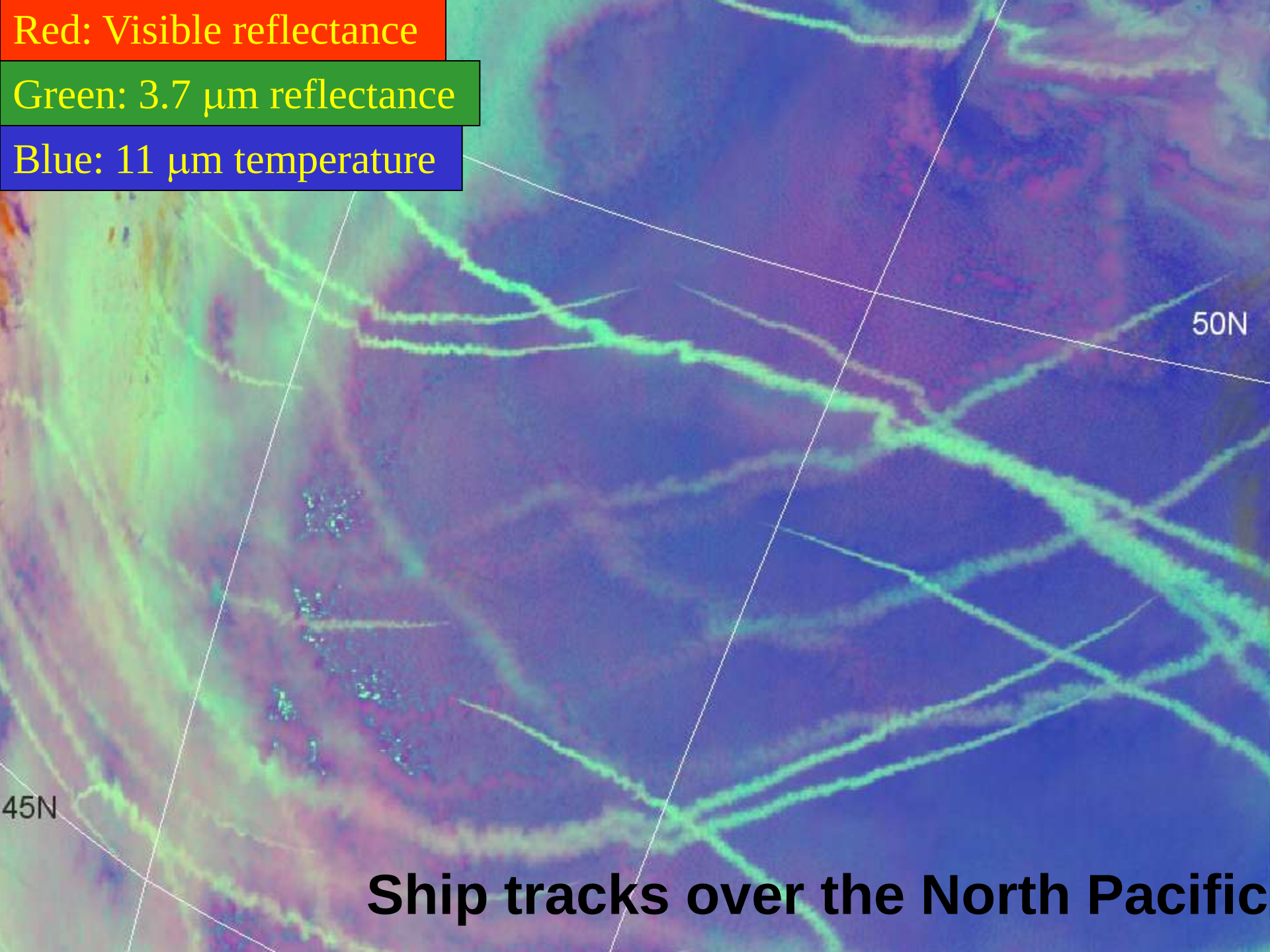
Areas of specialty:
Cloud-aerosol interactions,
precipitation and climate.
Severe convective storms.
Remote sensing of clouds.



Red: Visible reflectance

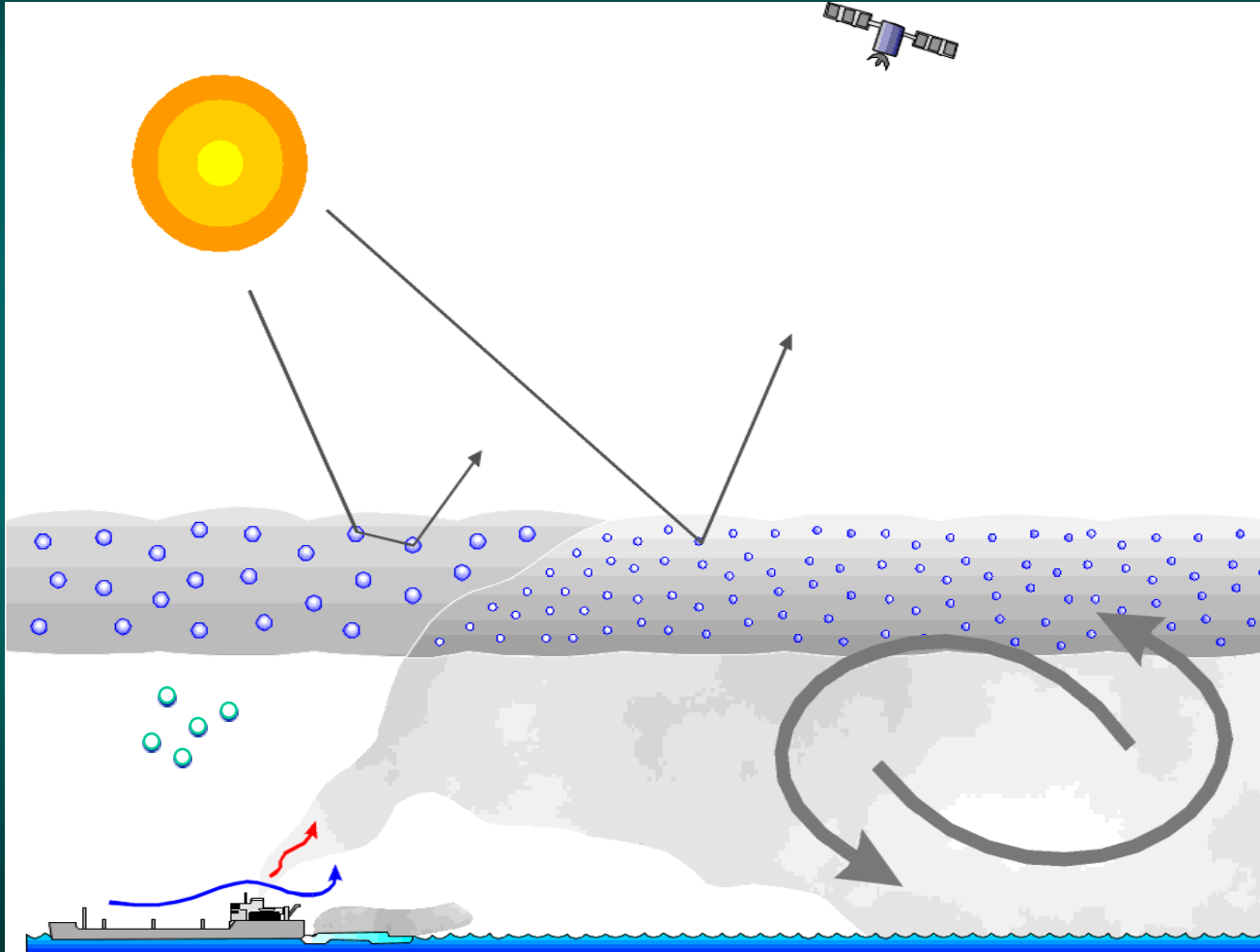
Green: 3.7 μm reflectance

Blue: 11 μm temperature

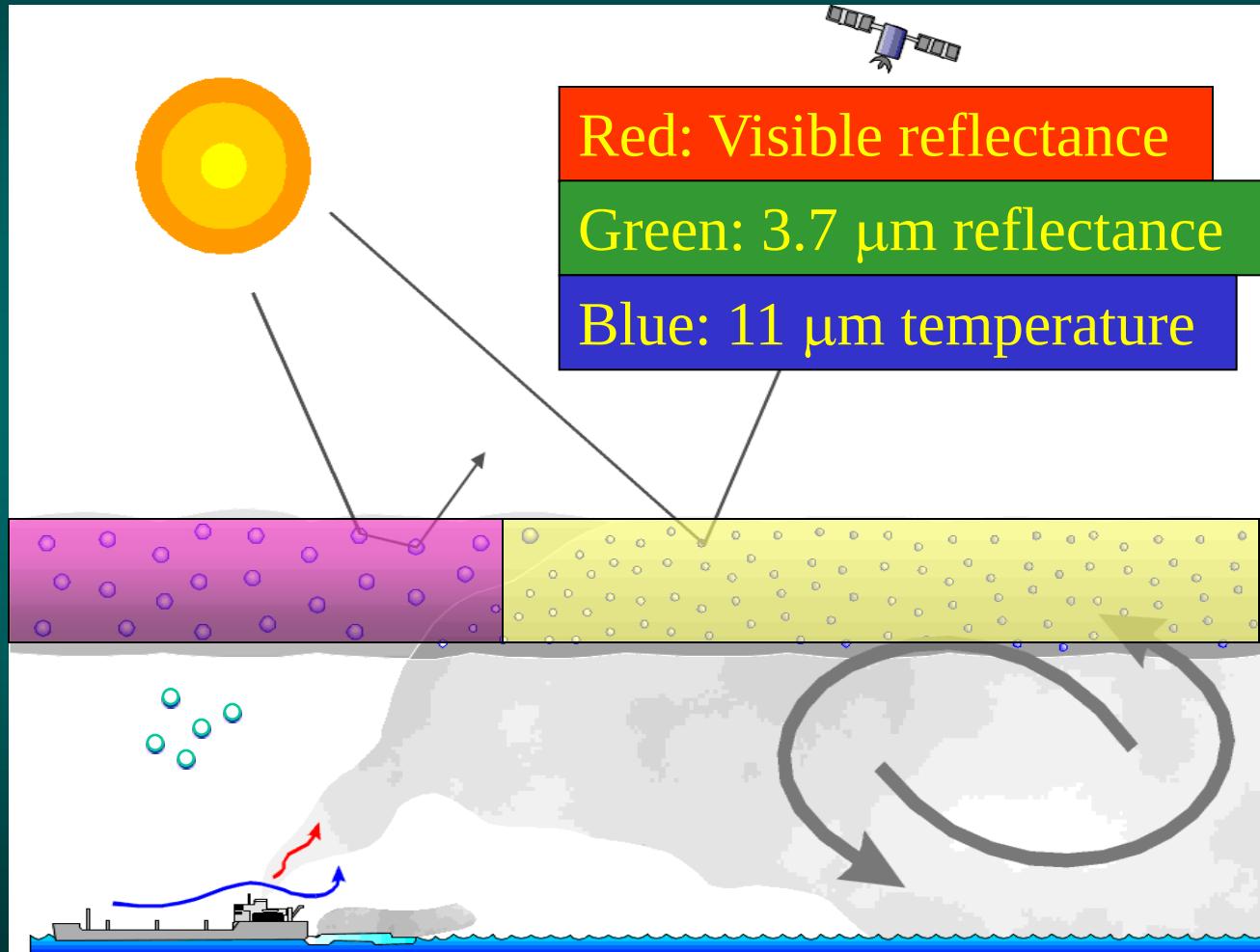


Ship tracks over the North Pacific

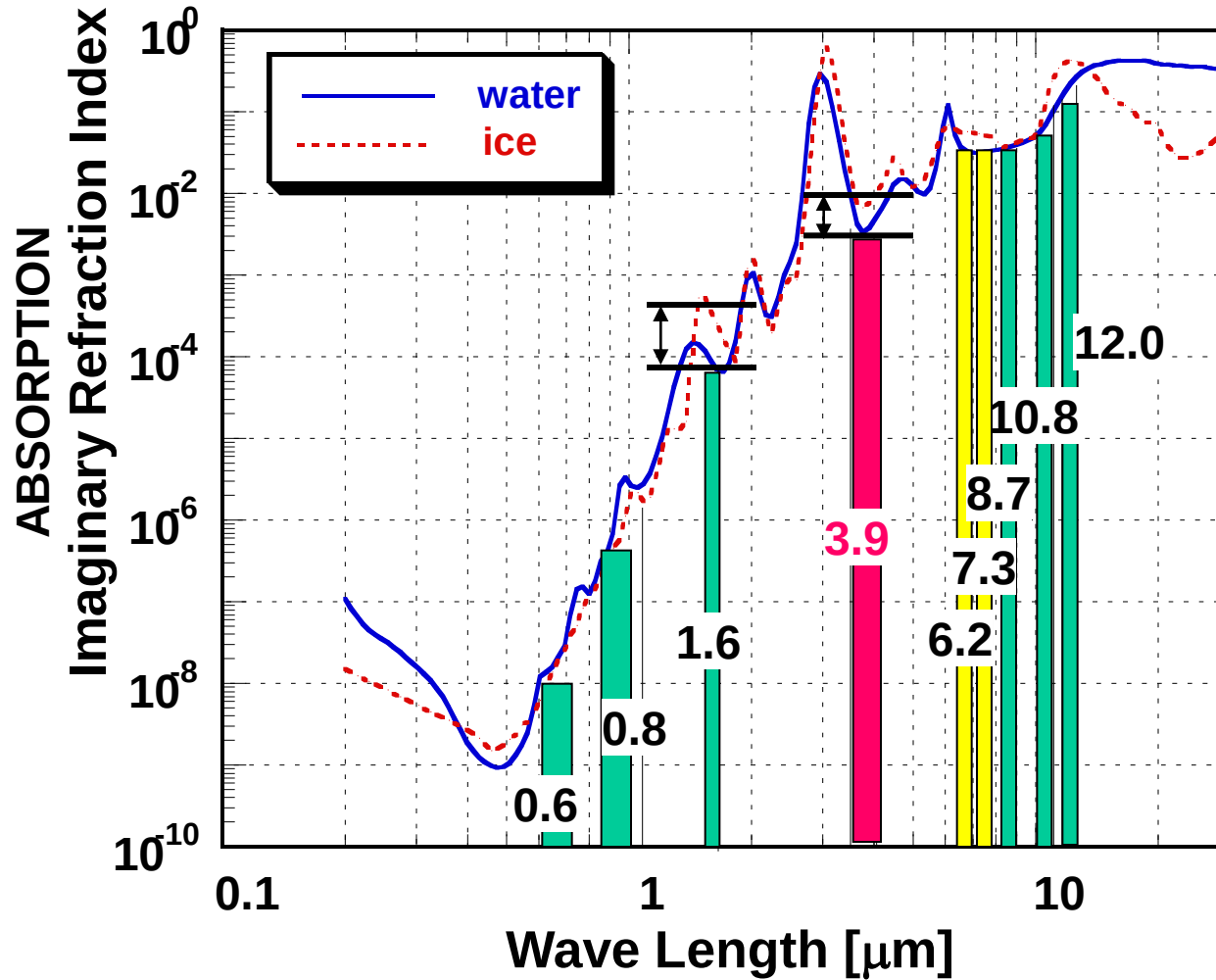
Ship Track Formation


$$\begin{aligned} N &\sim 40 \text{ cm}^{-3} \\ W &\sim 0.30 \text{ g m}^{-3} \\ r_e &\sim 11.2 \text{ } \mu\text{m} \end{aligned}$$
$$\begin{aligned} N &\sim 100 \text{ cm}^{-3} \\ W &\sim 0.75 \text{ g m}^{-3} \\ r_e &\sim 10.5 \text{ }\mu\text{m} \end{aligned}$$

Ship Track Formation

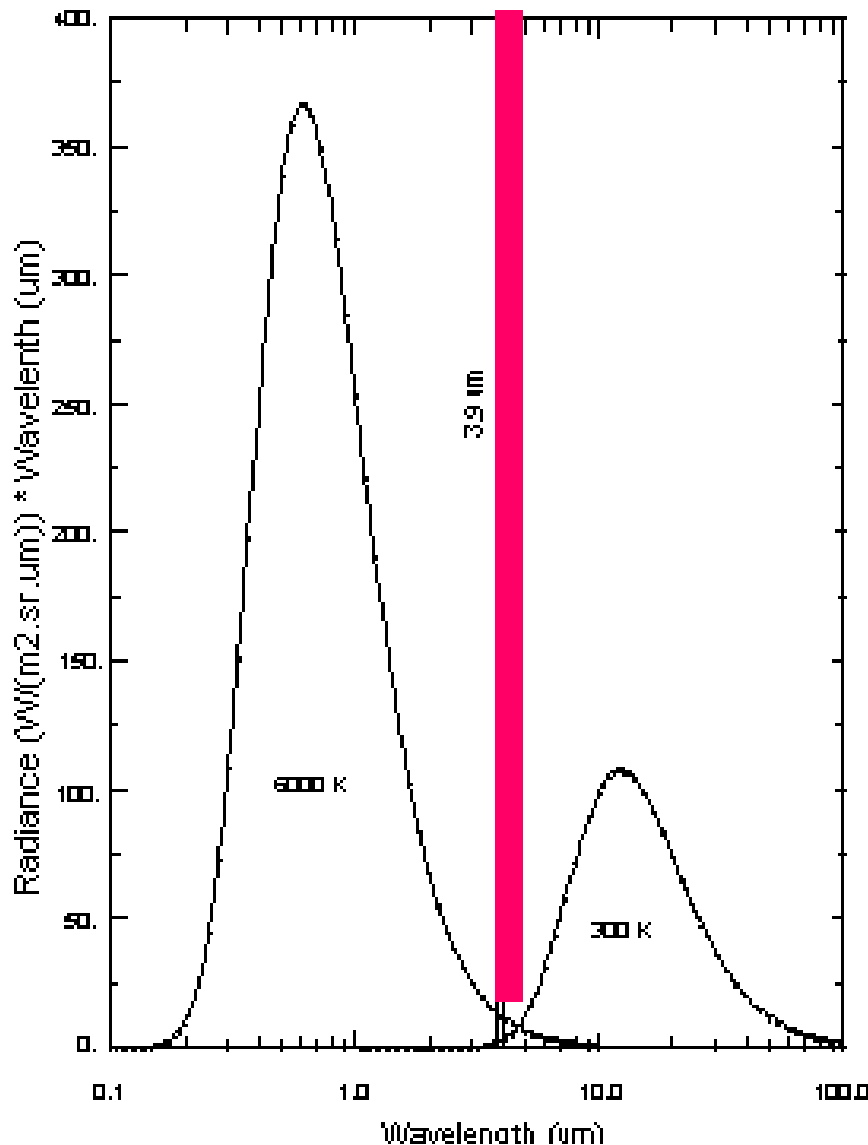


How can we detect from space the size of microscopic cloud particles?



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 .

SEVIRI CHANNELS: IR3.9 μm



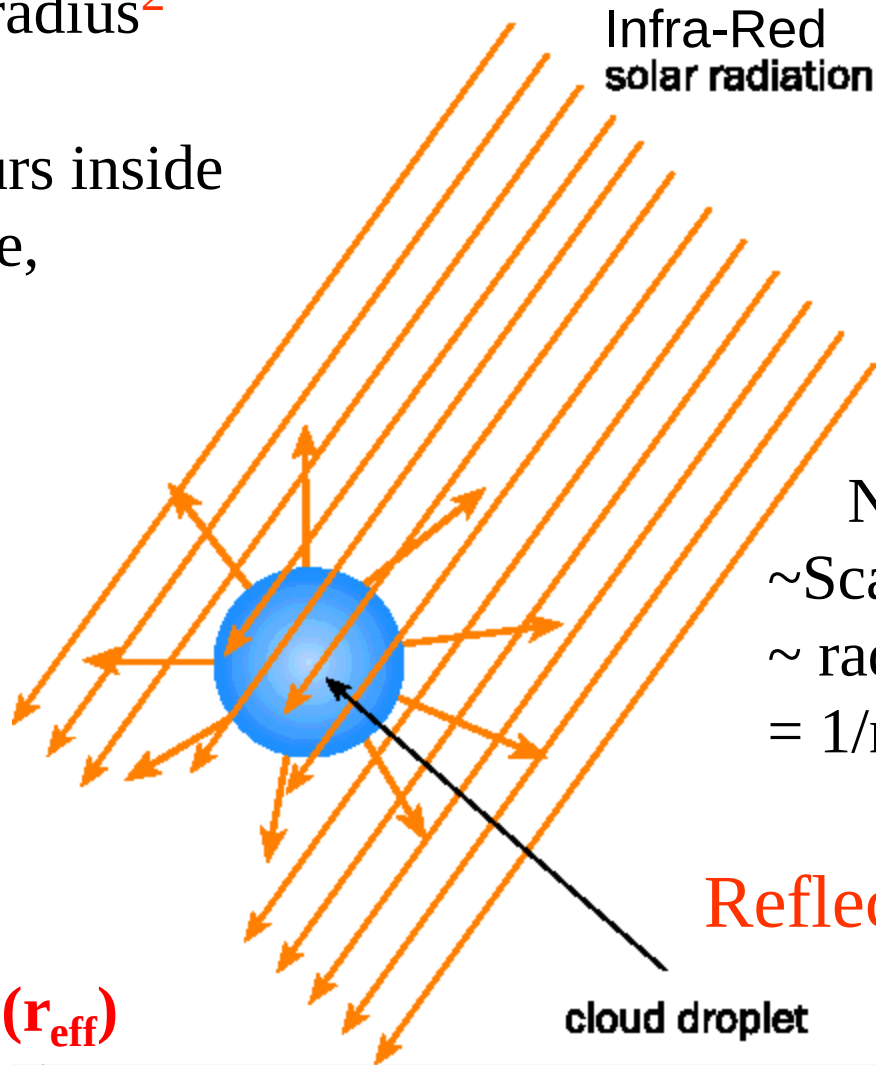
Planck blackbody radiance curves

Signal in IR3.9 channel comes from reflected solar and emitted thermal radiation.

For best results the thermal emission should be subtracted from the 3.9 μm radiance.

Scattering occurs on the
drop surface, $\sim \text{radius}^2$

Absorption occurs inside
The drop volume,
 $\sim \text{radius}^3$



Net reflectance
 $\sim \text{Scattering} / \text{Absorption}$
 $\sim \text{radius}^2 / \text{radius}^3$
 $= 1/\text{radius}$

Reflectance $\sim \text{Radius}^{-1}$

Definition of
Effective Radius (r_{eff})
of cloud droplets:

Sum of volumes / sum of surface areas
of the droplets in the measured cloud volume



Hyderabad
26.9.2010

$CCN_{0.6} = 2500 \text{ cm}^{-3}$
Max cloud drops = 600 cm^{-3}

$CCN_{0.6} = 200 \text{ cm}^{-3}$
Max cloud drops = 120 cm^{-3}

Bay of Bengal
26.9.2010

$CCN_{0.6} = 120 \text{ cm}^{-3}$
Max cloud drops = 60 cm^{-3}

Bay of Bengal
27.9.2010

$CCN_{0.6} = 6000 \text{ cm}^{-3}$
Max cloud drops = 1100 cm^{-3}

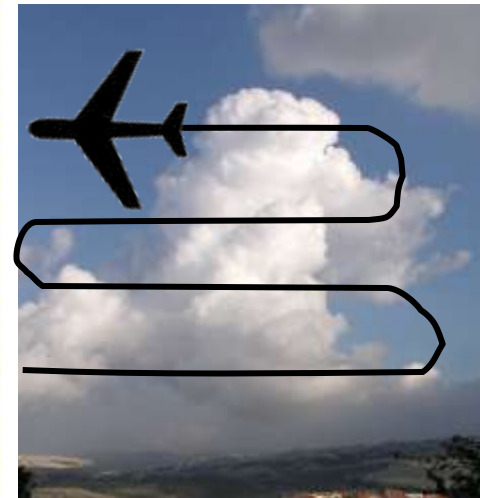
Bareilly
23.9.2009

Altitude (m)

8000
7000
6000
5000
4000
2000
1000
0

Cloud drop r_e [μm]

0 4 8 12 16 20



The relation between r_e and depth cloud depth above its base (D) is
¹¹uniquely related to CCN. D- r_e relations can be used for retrieving CCN.

Rosenfeld and Woodley, CAIPEEX-2 Final report to IITM.

MODIS Airborne Simulator-L1B

02-954-06

26 Jul 2002

18:44 GMT

Caribbean Sea

Flight level 20 km

Resolution 50 m at NADIR

Swath $\pm 45^\circ$, With=37 km

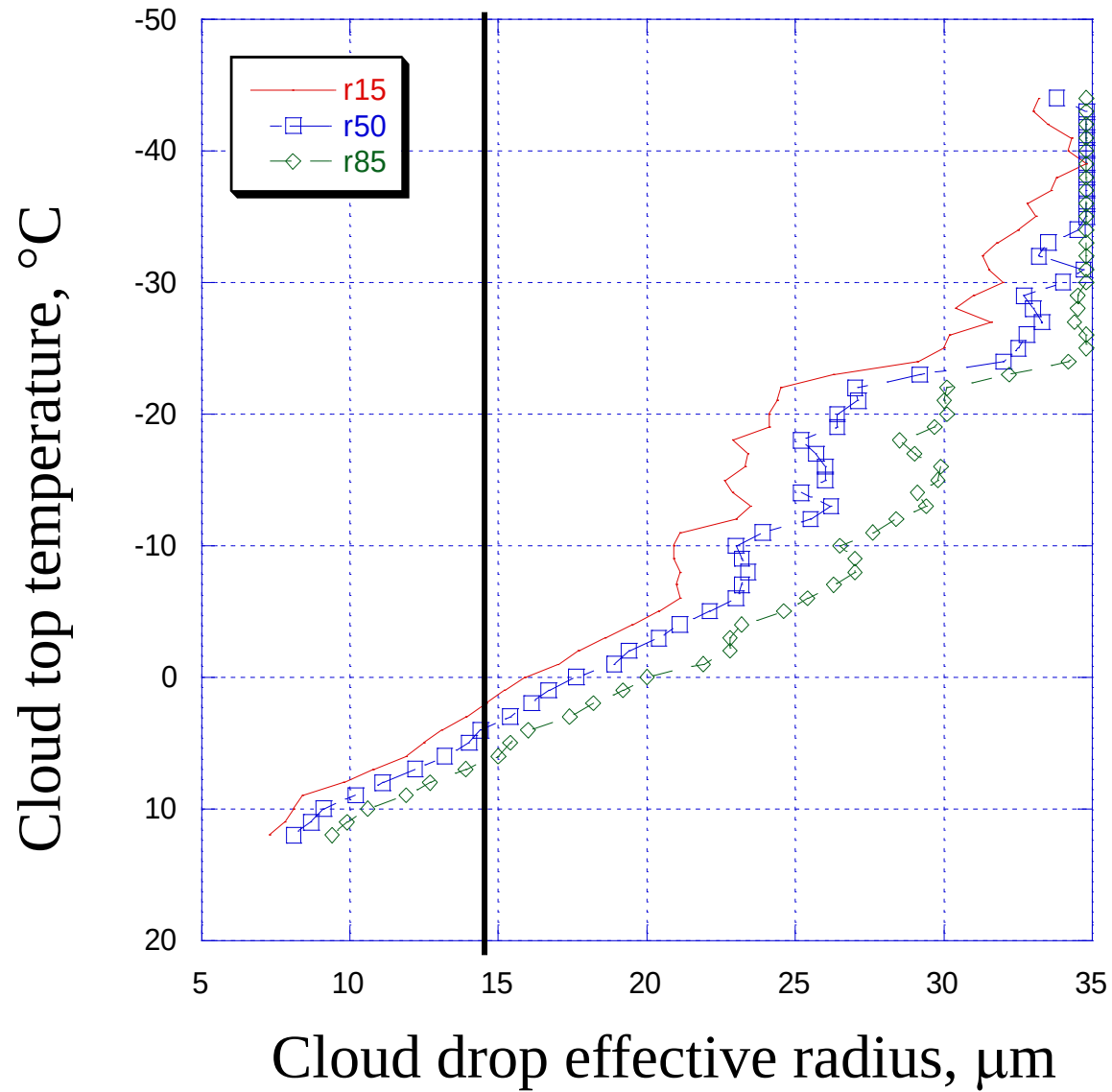
Red: 0.63 μm

Green: 2.06 μm

Blue: 2.11/2.21 μm

TRe37L--180_00_02954_06_lon_-82.475_lat_14.073 20020726

MASTR300-180_02954_06_lon_-82.475_lat_14.073



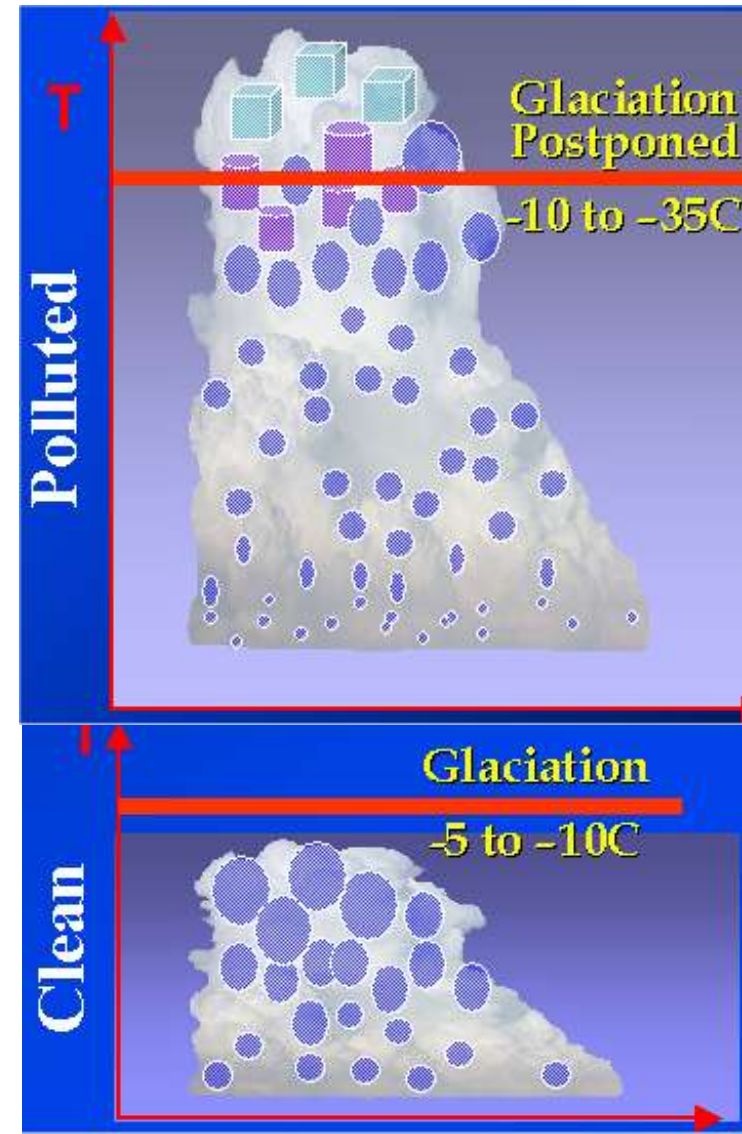
7/30/2013

Convective clouds can be characterized by three cloud top properties that can be detected by satellites and represented by respective three RGB components:

1. Temperature, lower for higher tops;

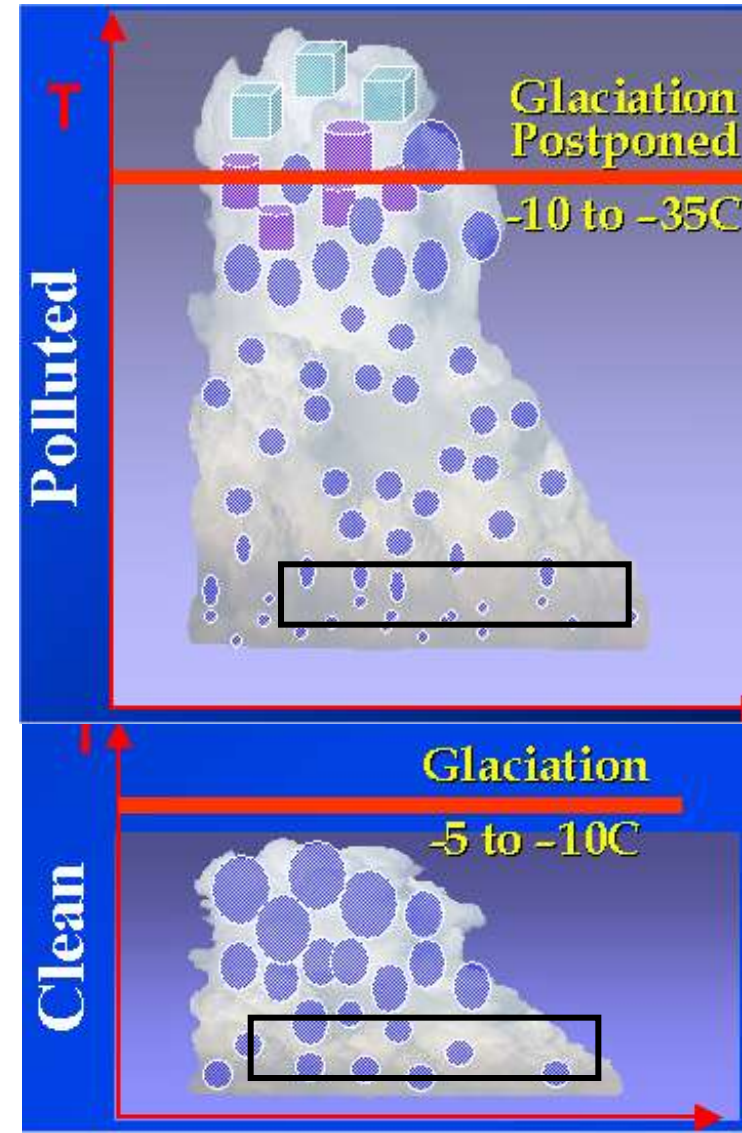
2. Visible brightness, reflecting more solar radiation for thicker clouds with more water and ice;

3. Cloud particle size and phase (water or ice), having larger drops for clouds with greater depth. Drops appear larger when freezing at temperatures that can range between 0 and -38°C .



Q: What would be the RGB color of the low part of the cloud?

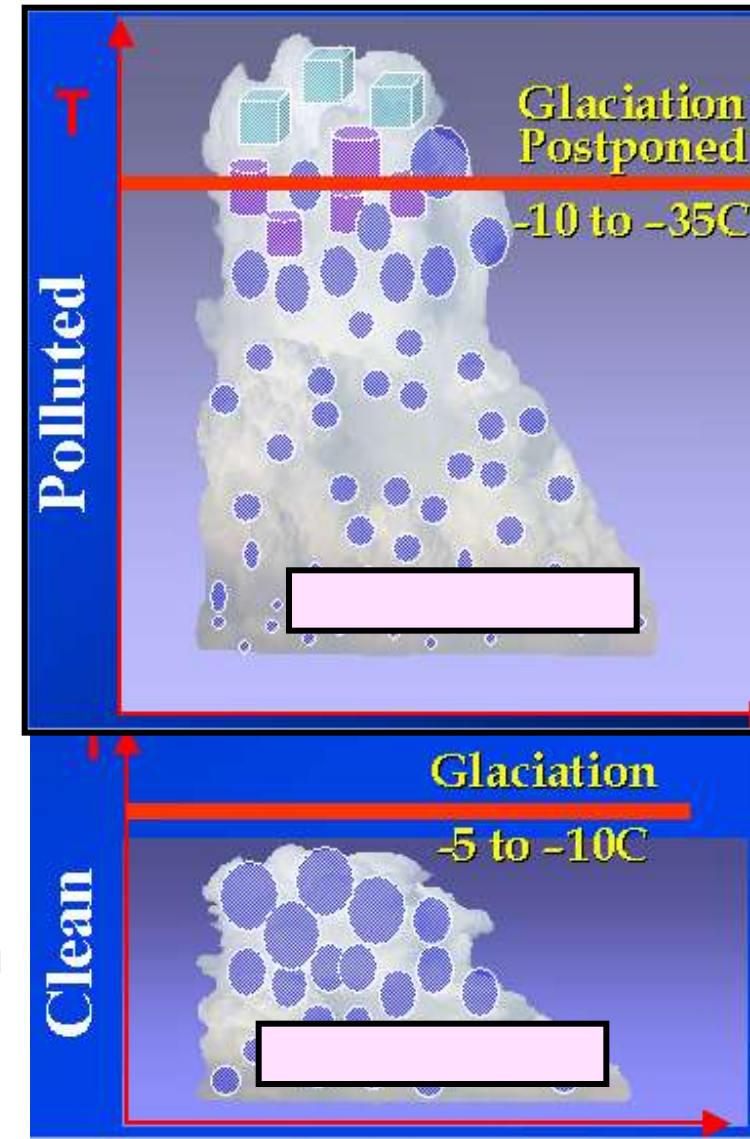
-  1. **Temperature, lower for higher tops;**
-  2. **Visible brightness, reflecting more solar radiation for thicker clouds with more water and ice;**
-  3. **Cloud particle size and phase (water or ice), having larger drops for clouds with greater depth. Drops appear larger when freezing at temperatures that can range between 0 and -38°C.**



Q: What would be the RGB color of the low part of the cloud?

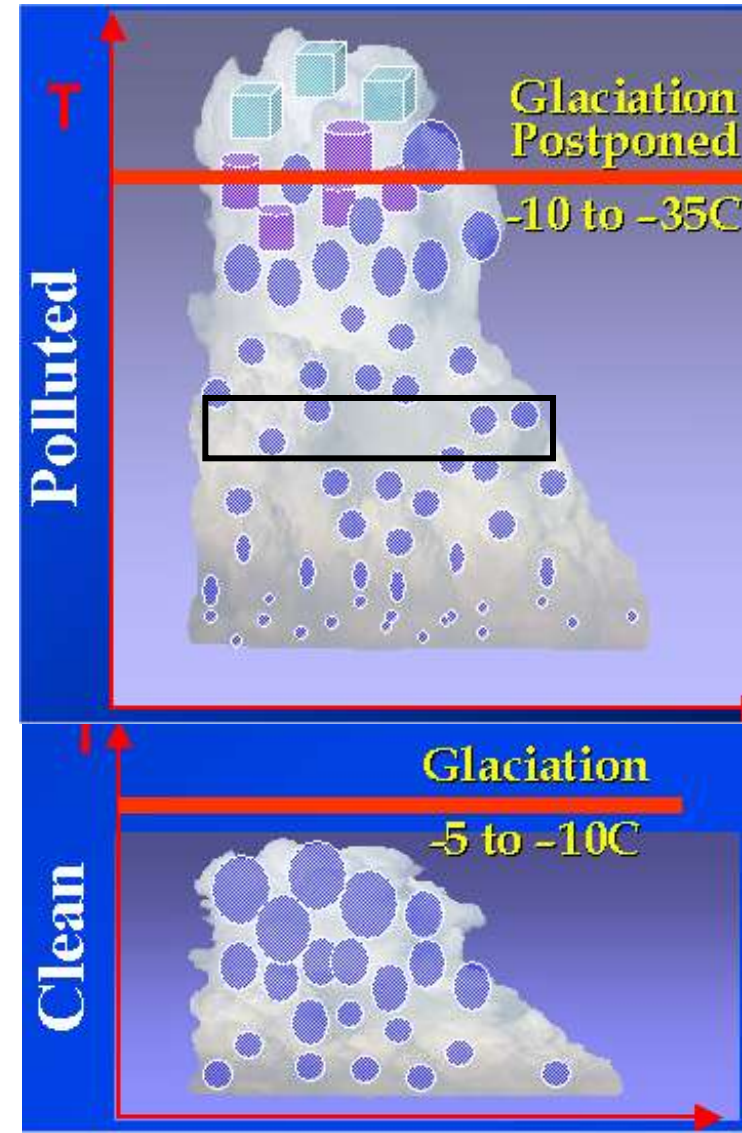
A: High T ■ + Visibly Bright ■ + Small Drops ■ = ■

- ↑ 1. Temperature, lower for higher tops;
- ↑ 2. Visible brightness, reflecting more solar radiation for thicker clouds with more water and ice;
- ↓ 3. Cloud particle size and phase (water or ice), having larger drops for clouds with greater depth. Drops appear larger when freezing at temperatures that can range between 0 and -38°C.



Cloud drops must be large for coalescing into rain drops!
Q: What color would be a cool cloud with **small** drops?

- ↑ 1. Temperature, lower for higher tops;
- ↑ 2. Visible brightness, reflecting more solar radiation for thicker clouds with more water and ice;
- ↓ 3. Cloud particle size and phase (water or ice), having larger drops for clouds with greater depth. Drops appear larger when freezing at temperatures that can range between 0 and -38°C .

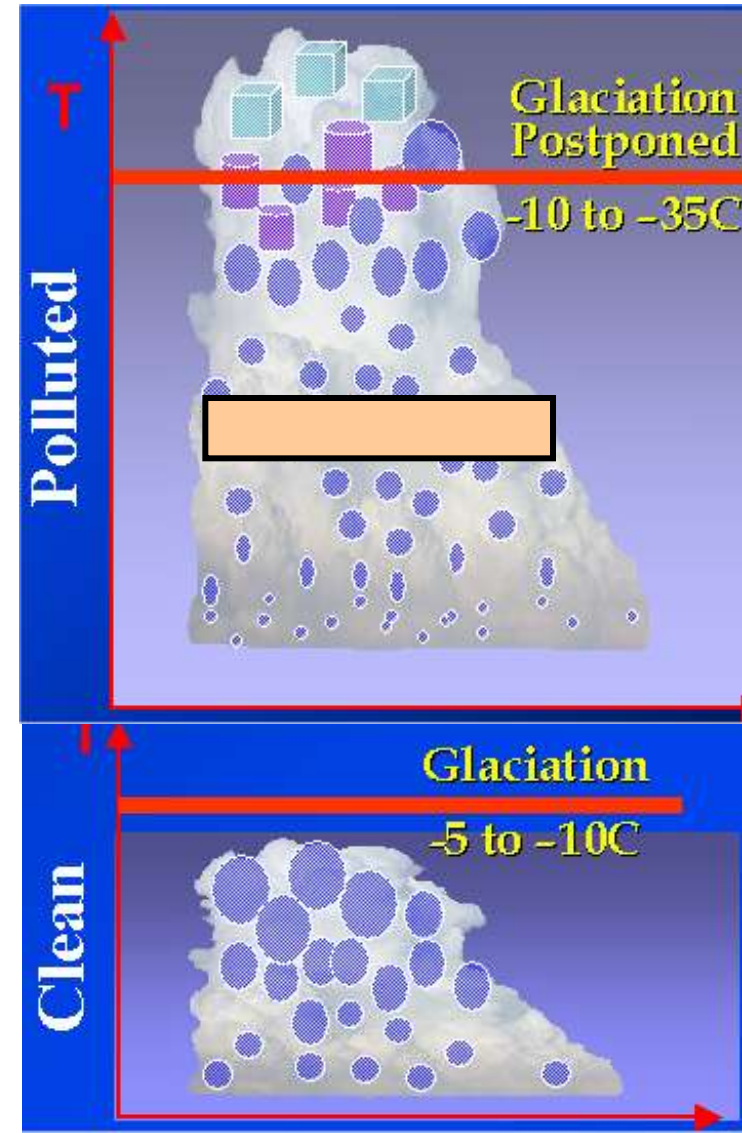


Cloud drops must be large for coalescing into rain drops!

Q: What color would be a cool cloud with **small** drops?

A: Medium T  + Visibly Bright  + Small Drops  = 

-  1. Temperature, lower for higher tops;
-  2. Visible brightness, reflecting more solar radiation for thicker clouds with more water and ice;
-  3. Cloud particle size and phase (water or ice), having larger drops for clouds with greater depth. Drops appear larger when freezing at temperatures that can range between 0 and -38°C.

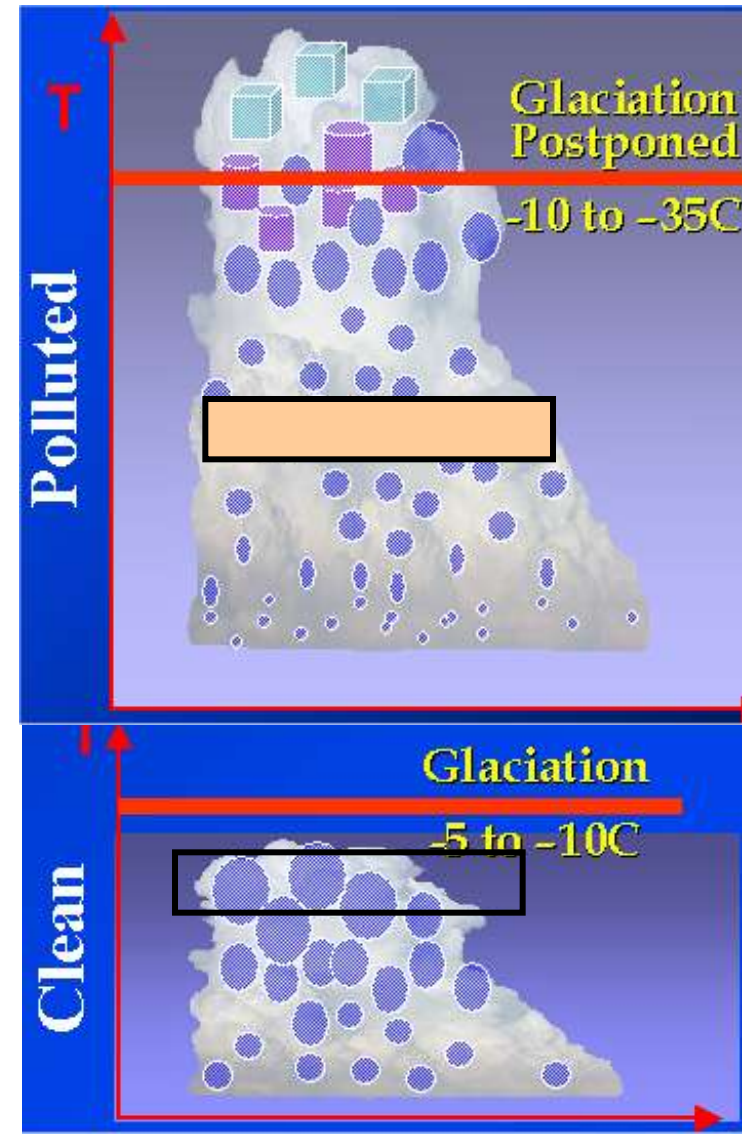


Cloud drops must be large for coalescing into rain drops!

Q: What color would be a cool cloud with **large** drops?

A: Medium T  + Visibly Bright  + Large Drops  = 

-  1. Temperature, lower for higher tops;
-  2. Visible brightness, reflecting more solar radiation for thicker clouds with more water and ice;
-  3. Cloud particle size and phase (water or ice), having larger drops for clouds with greater depth. Drops appear larger when freezing at temperatures that can range between 0 and -38°C.

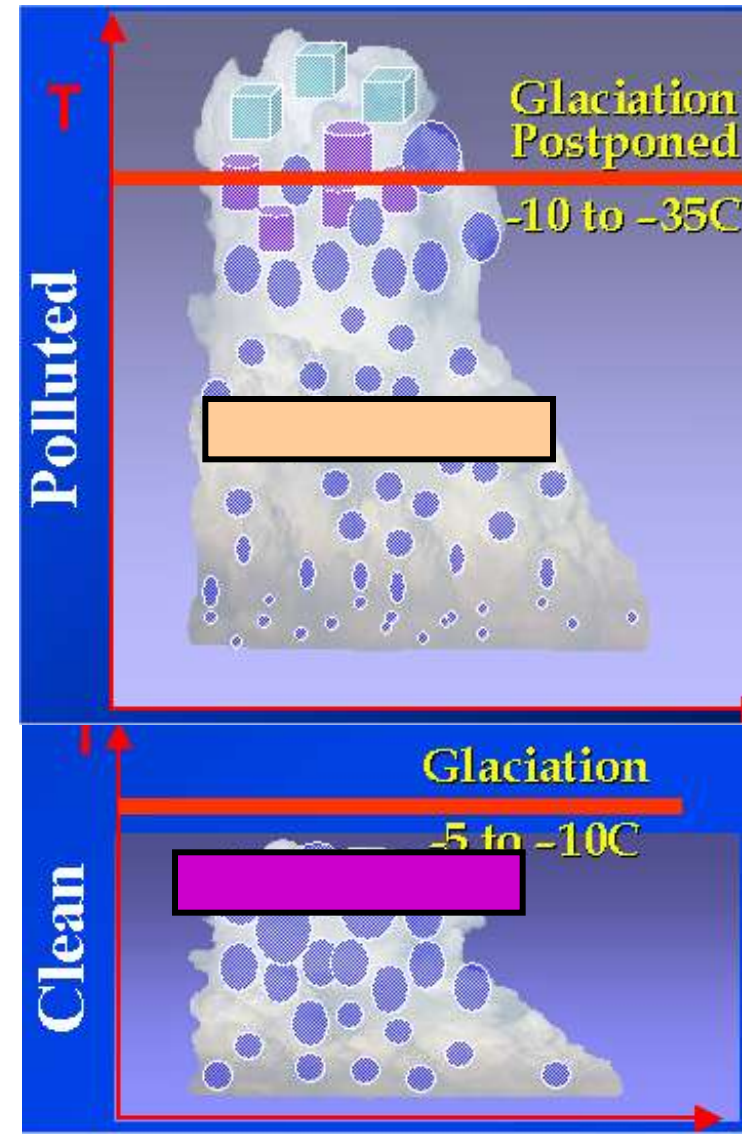


Cloud drops must be large for coalescing into rain drops!

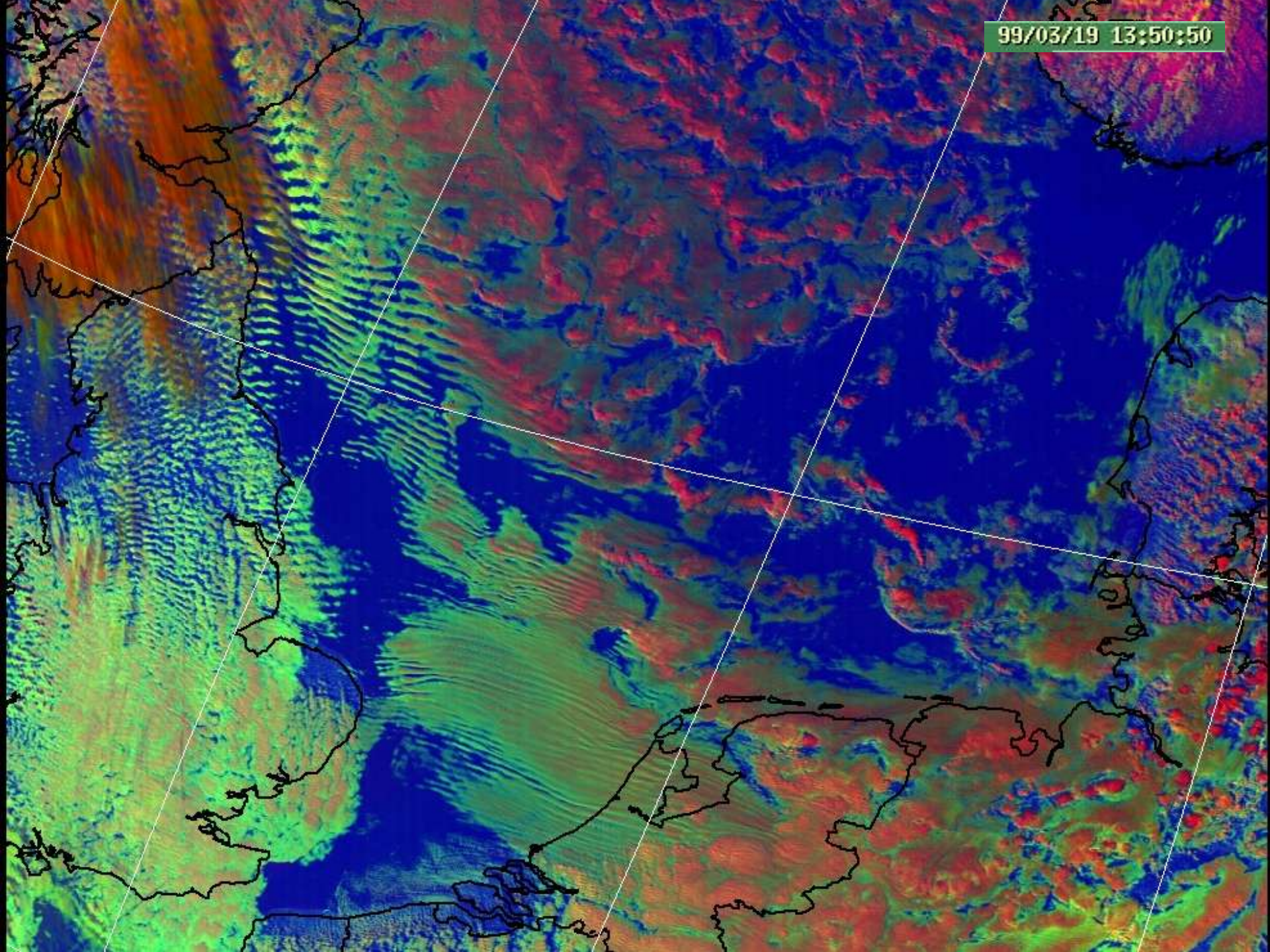
Q: What color would be a cool cloud with **large** drops?

A: Medium T ■ + Visibly Bright ■ + Large Drops ■ = ■

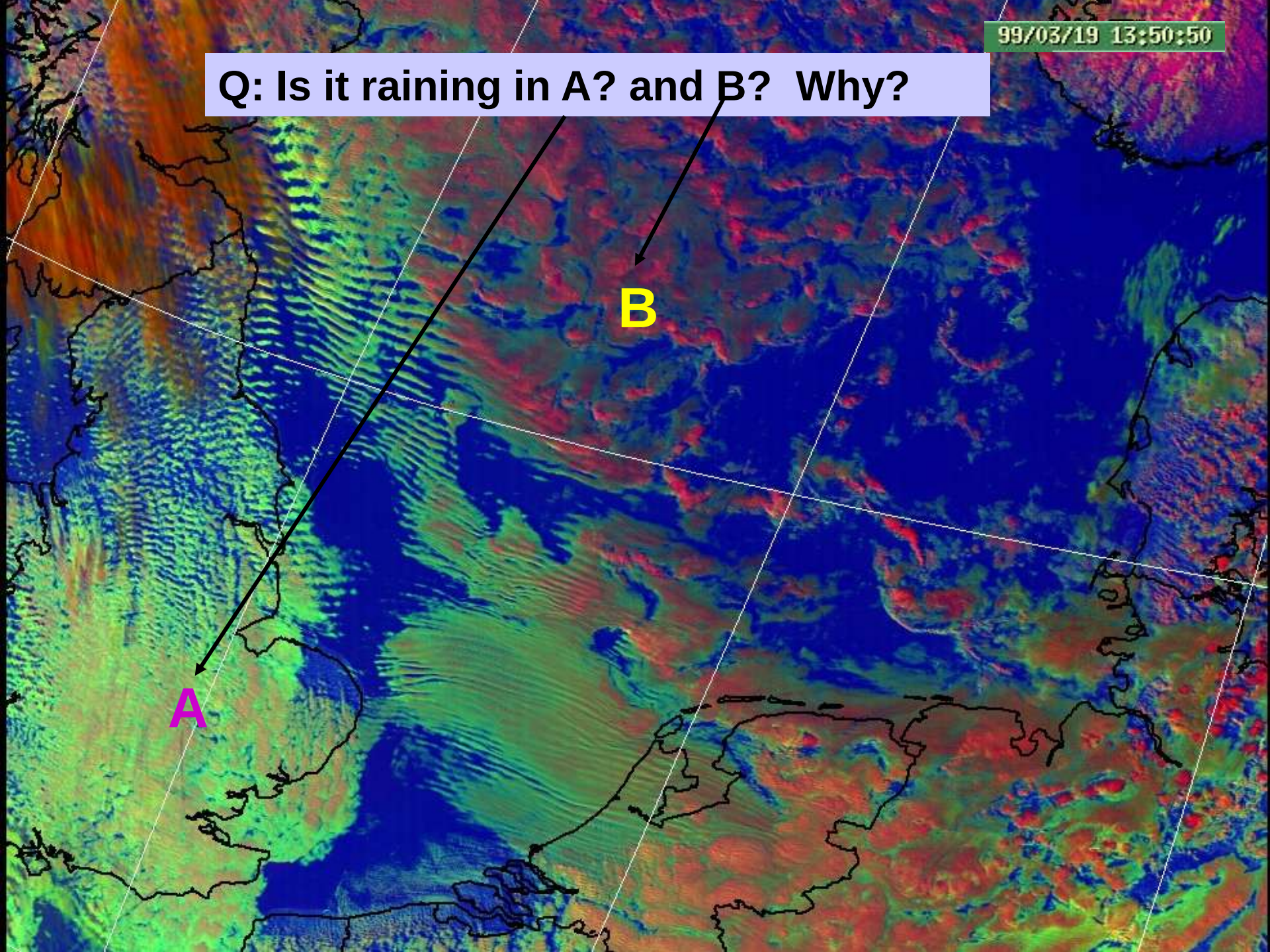
- ↑ 1. Temperature, lower for higher tops;
- ↑ 2. Visible brightness, reflecting more solar radiation for thicker clouds with more water and ice;
- ↓ 3. Cloud particle size and phase (water or ice), having larger drops for clouds with greater depth. Drops appear larger when freezing at temperatures that can range between 0 and -38°C.



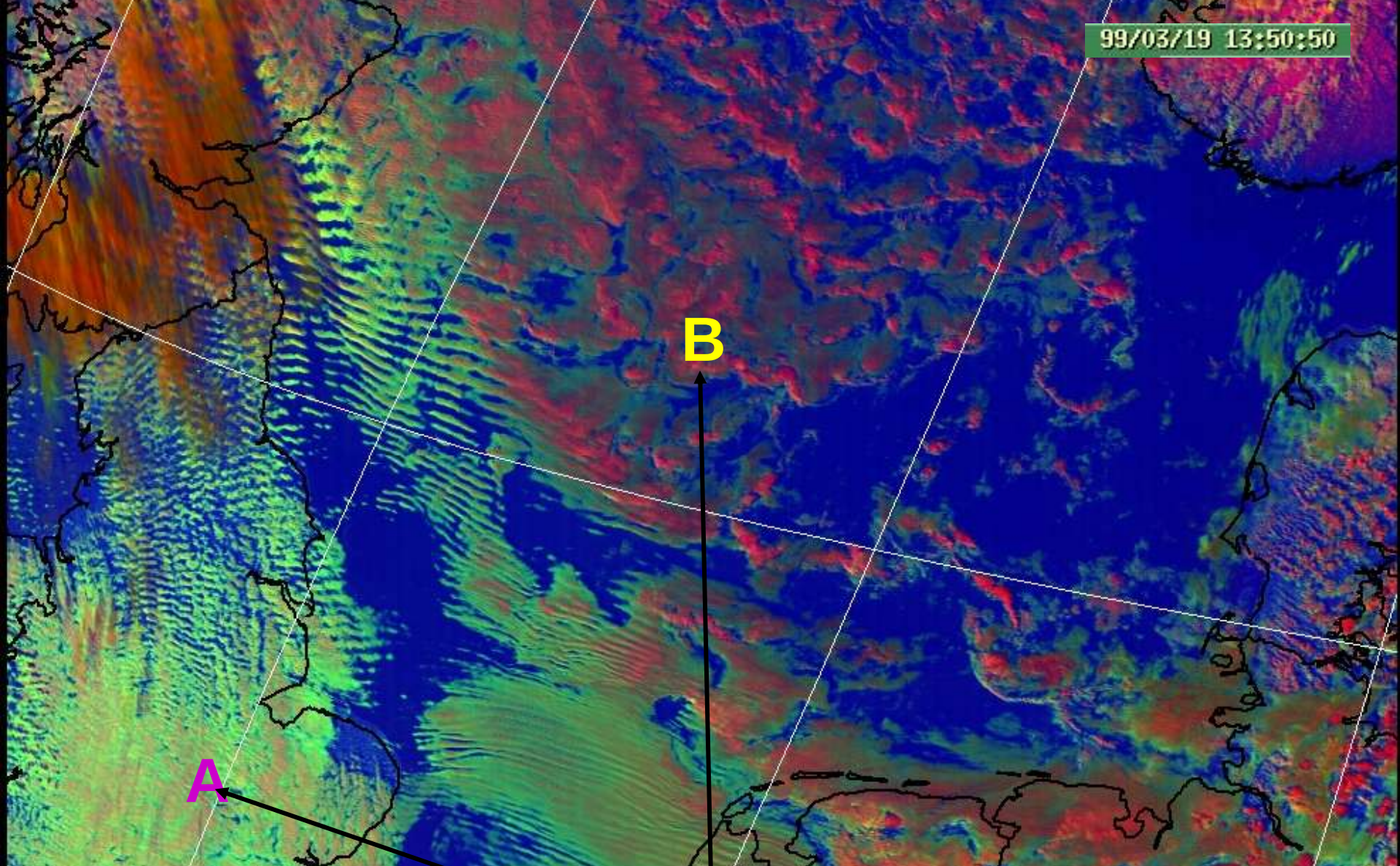
99/03/19 13:50:50



Q: Is it raining in A? and B? Why?



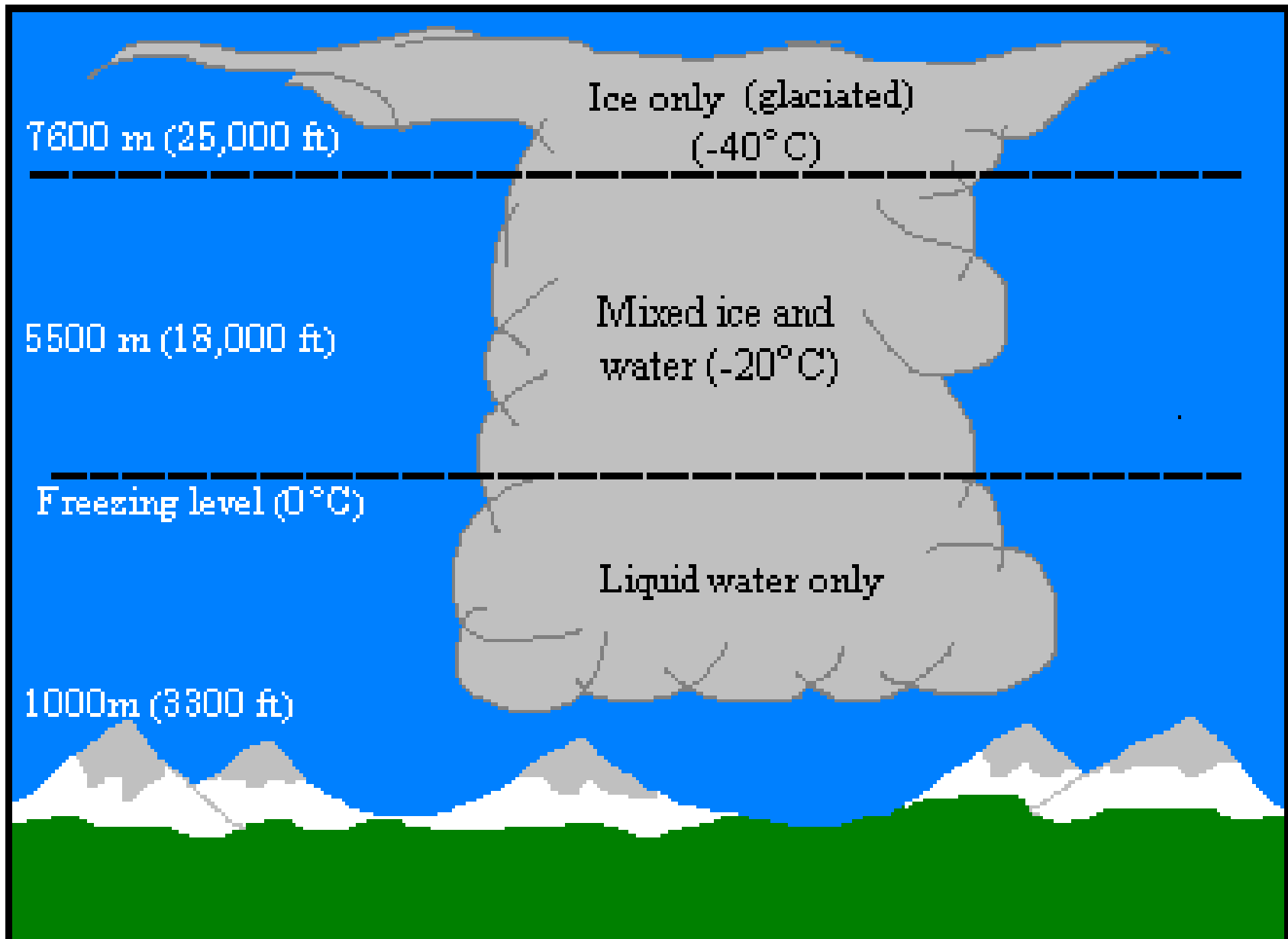
99/03/19 13:50:50



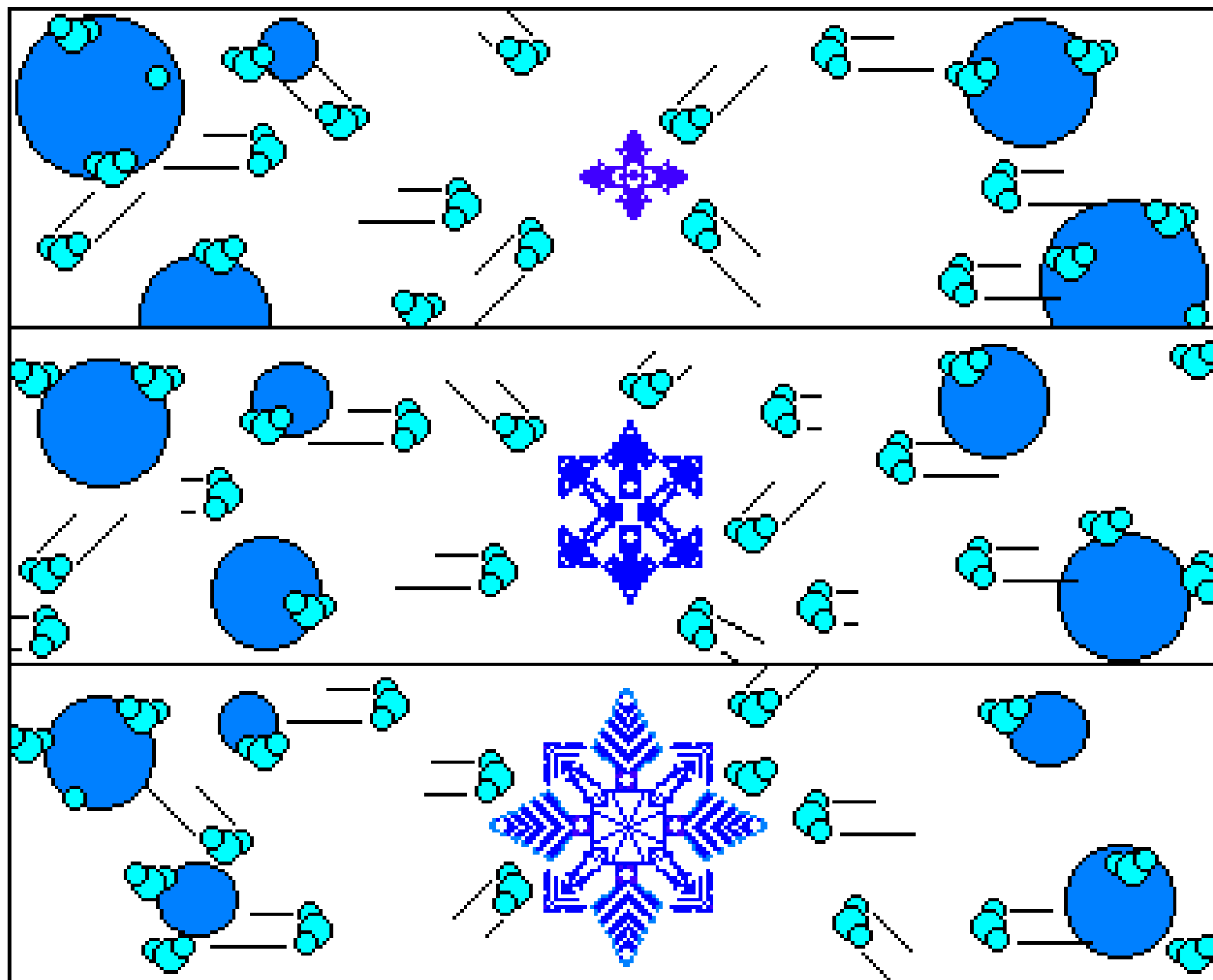
Q: Is it raining in A? and B? Why?

A: Not raining in A, because the cloud drops are small.

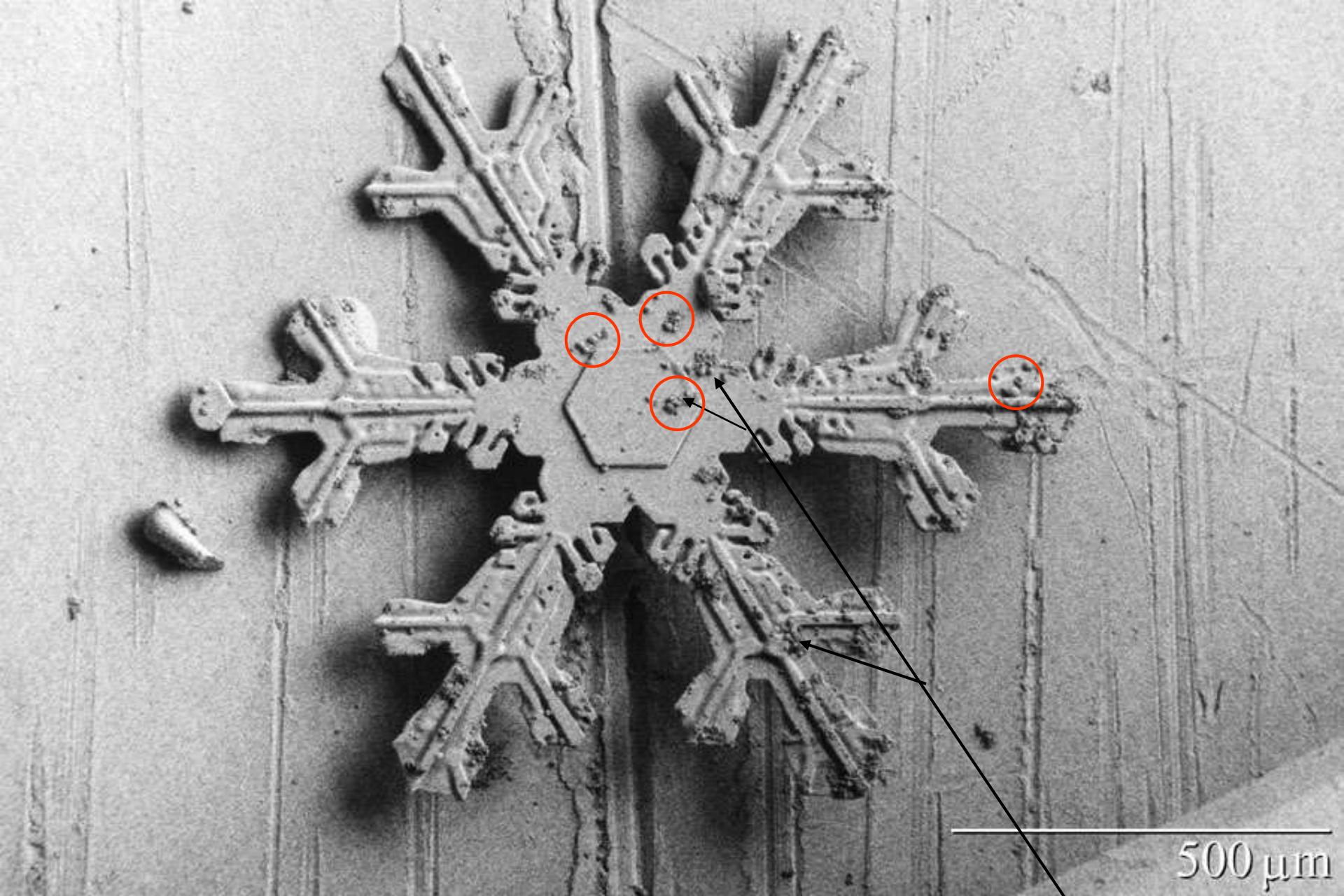
A: It is raining in B, because the cloud drops are large.



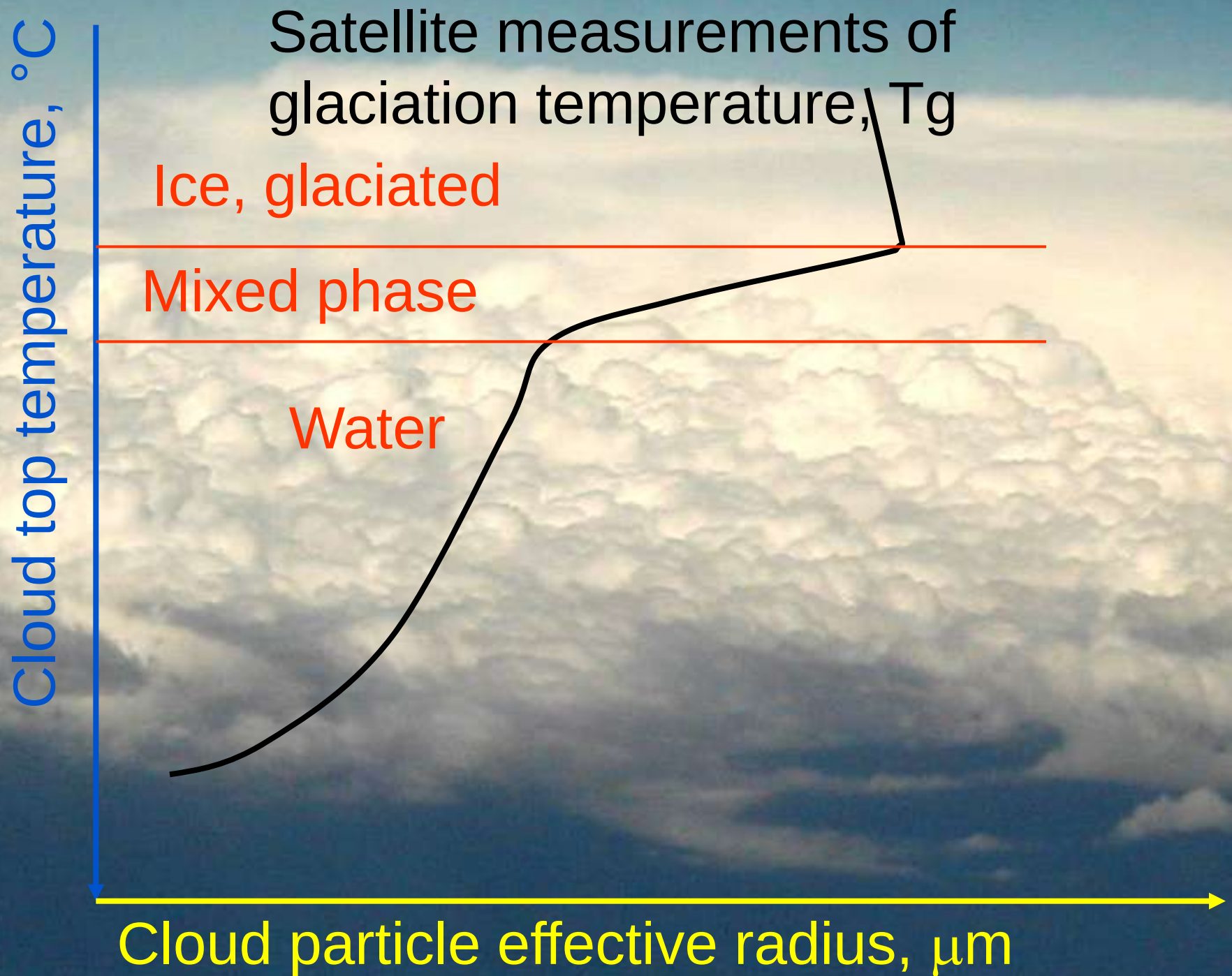
How can we distinguish between water and ice cloud?



Bergeron process

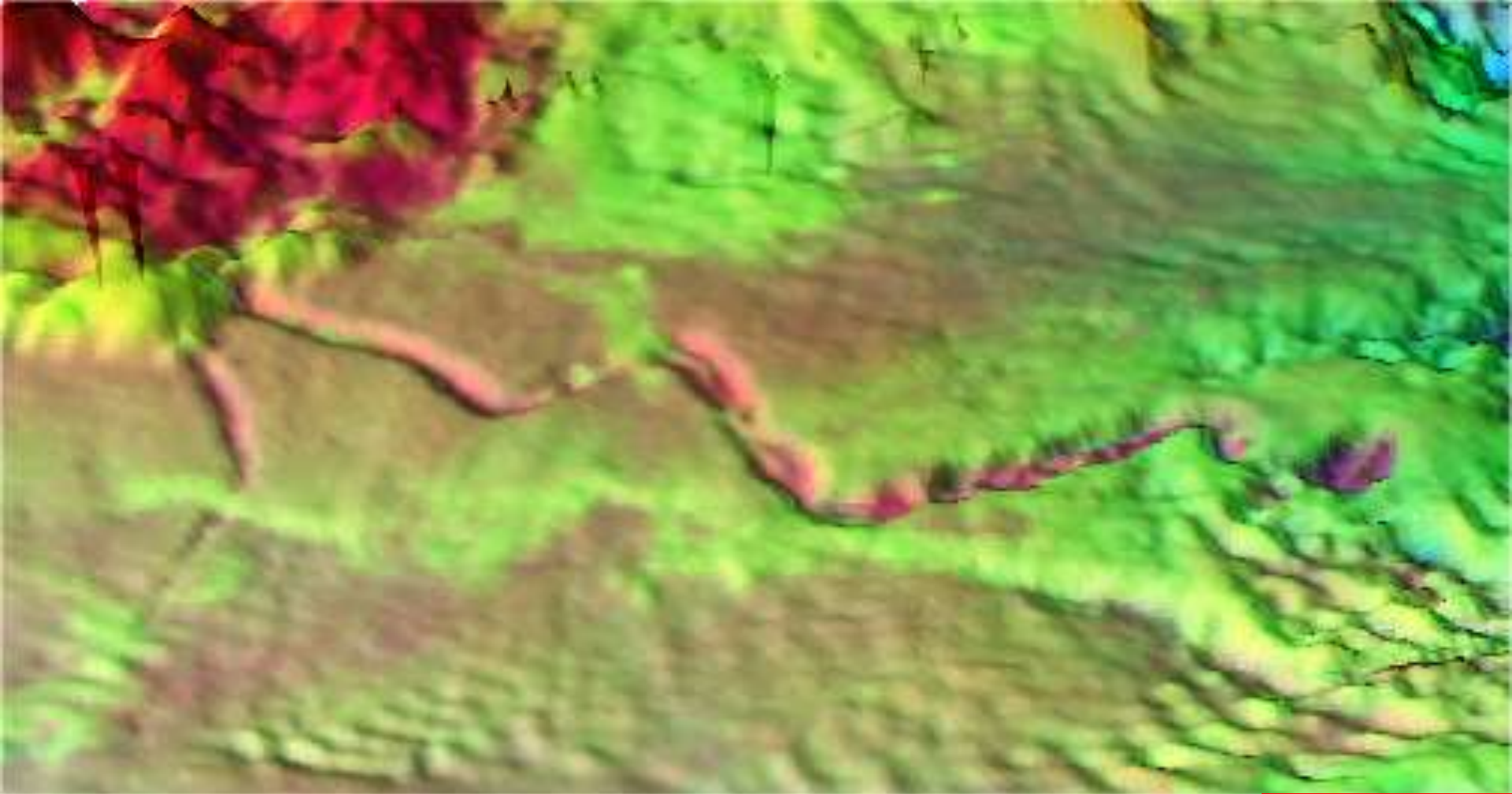


Large ice crystal collects small supercooled cloud drops?





The general view of the dry ice-seeded racetrack pattern in supercooled cloud layer 37 minutes after the start of the seeding and 24 minutes after the end of the seeding. The cloud layer extended between 4500 and 6800 feet over Utica, New York, with top temperature of -5.6°C . The picture was taken at 24 November 1948 15:21 from an altitude of 17,630 feet. (From Langmuir, 1961).



0.8 μm

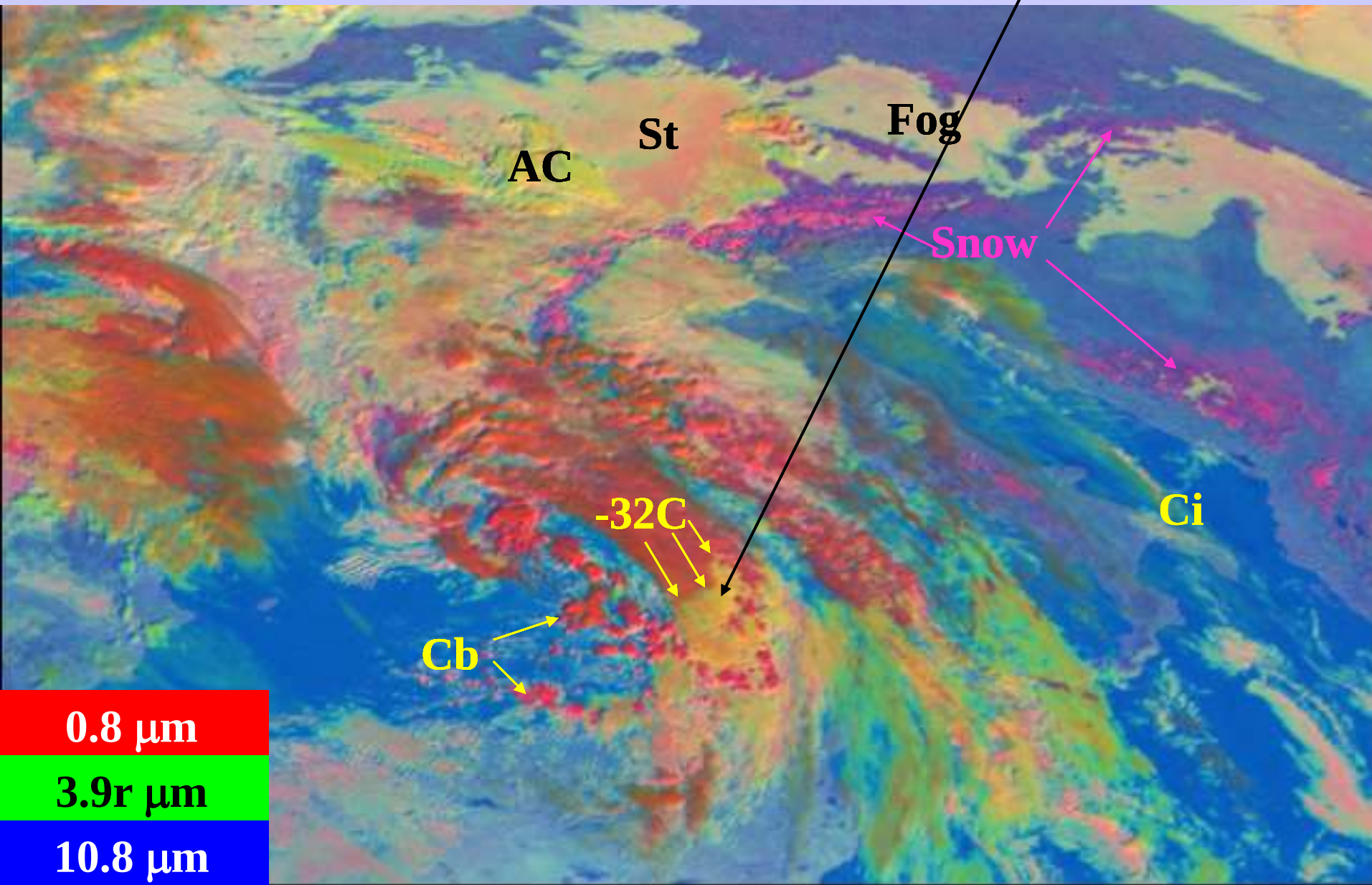
3.9 μm

10.8 μm

Daniel Rosenfeld, Xing Yu and Jin Dai, 2005: **Satellite retrieved microstructure of AgI seeding tracks in supercooled layer clouds.** *Journal of Applied Meteorology*, **44**, 760-767

Cold cloud with small supercooled drops:

Low T ■ + Visibly Bright ■ + Small Drops ■ = ■

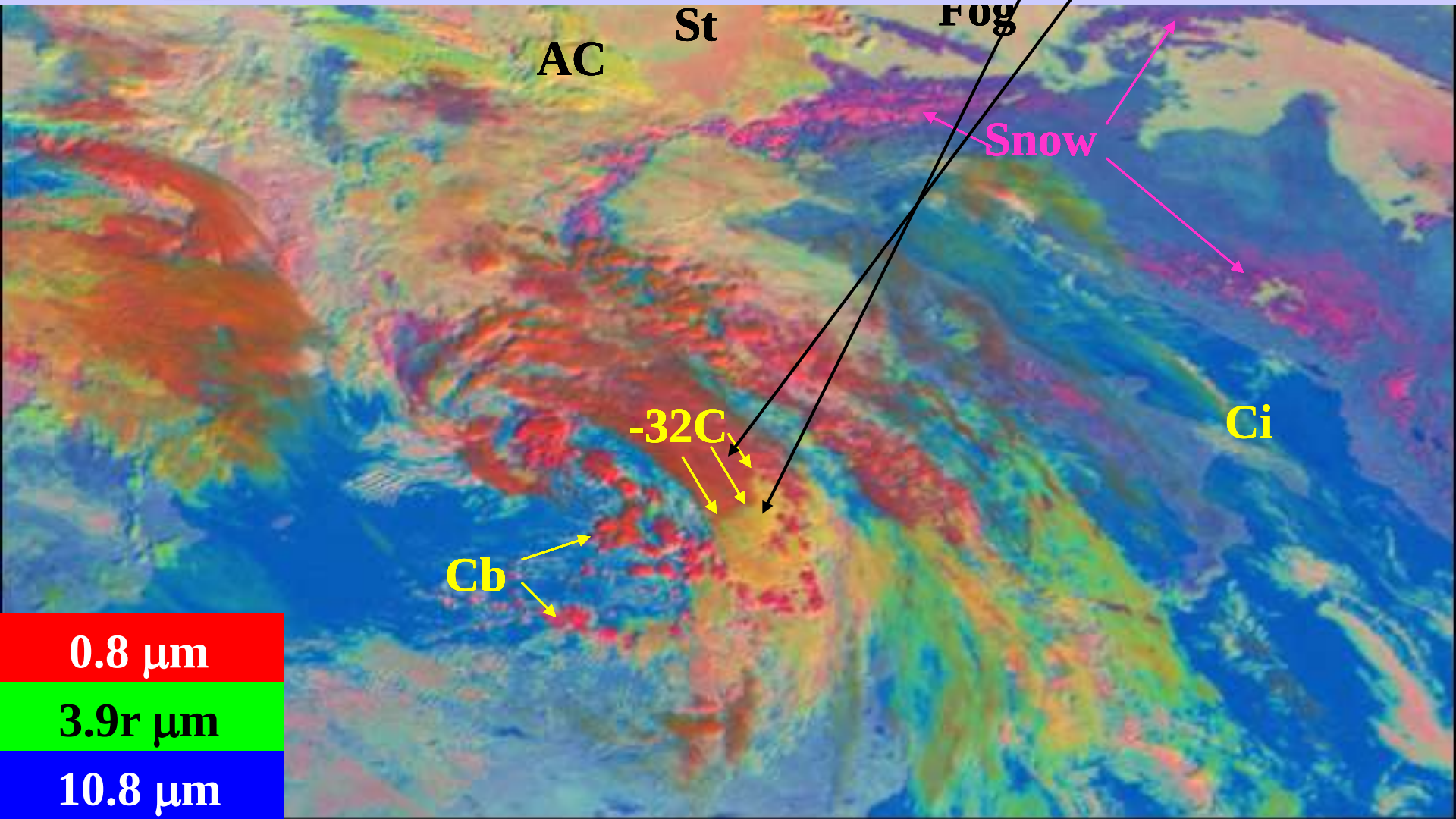


Cold cloud with small supercooled drops:

Low T ■ + Visibly Bright ■ + Small Drops ■ = ■

Cold cloud with large ice crystals:

Low T ■ + Visibly Bright ■ + Large Ice ■ = ■



0.8 μm

3.9 μm

10.8 μm

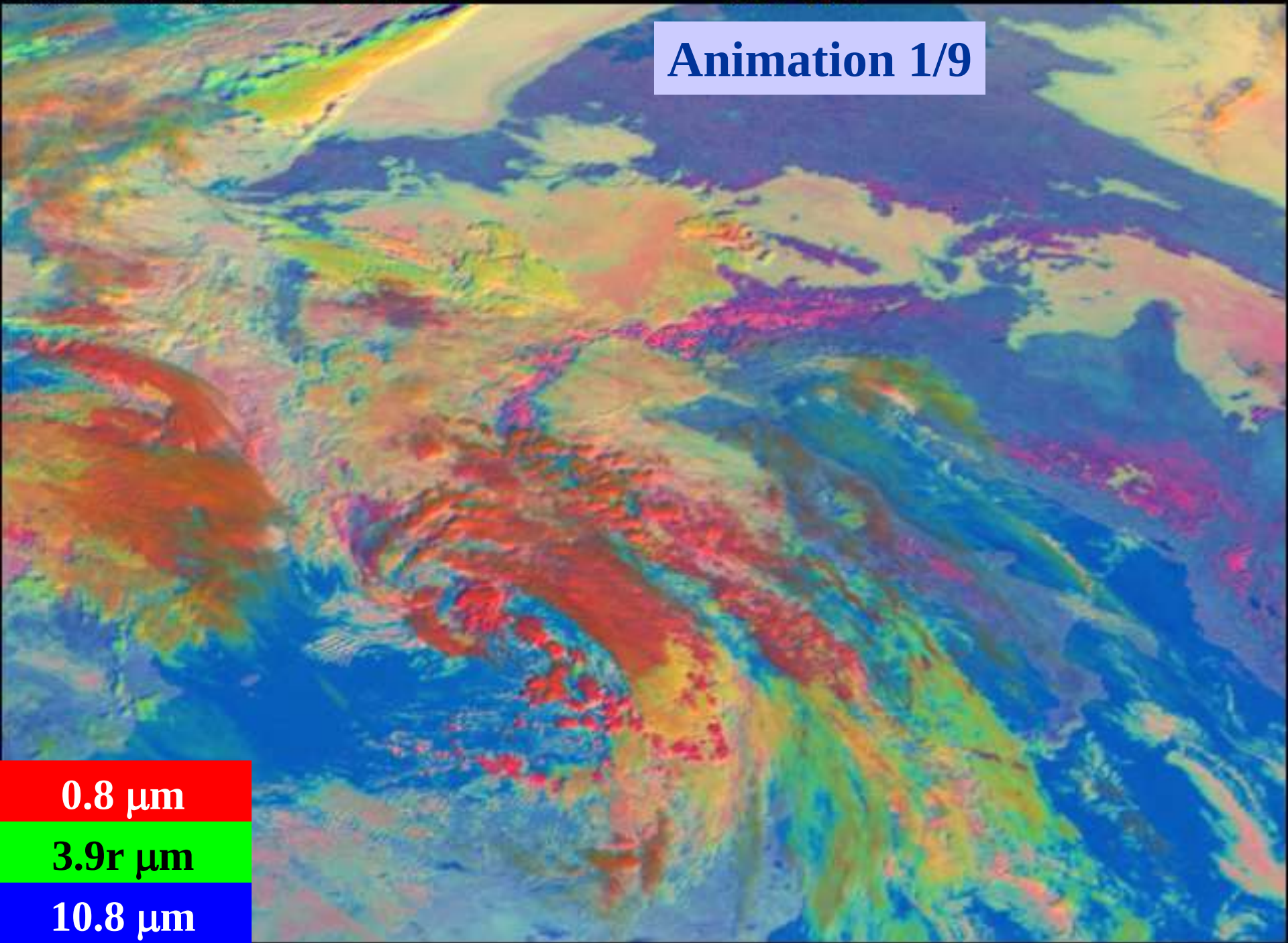
2003/12/19 10:27

CH02 0.8

CH04 3.9

CH09 10.8

Animation 1/9



0.8 μm
3.9 μm
10.8 μm

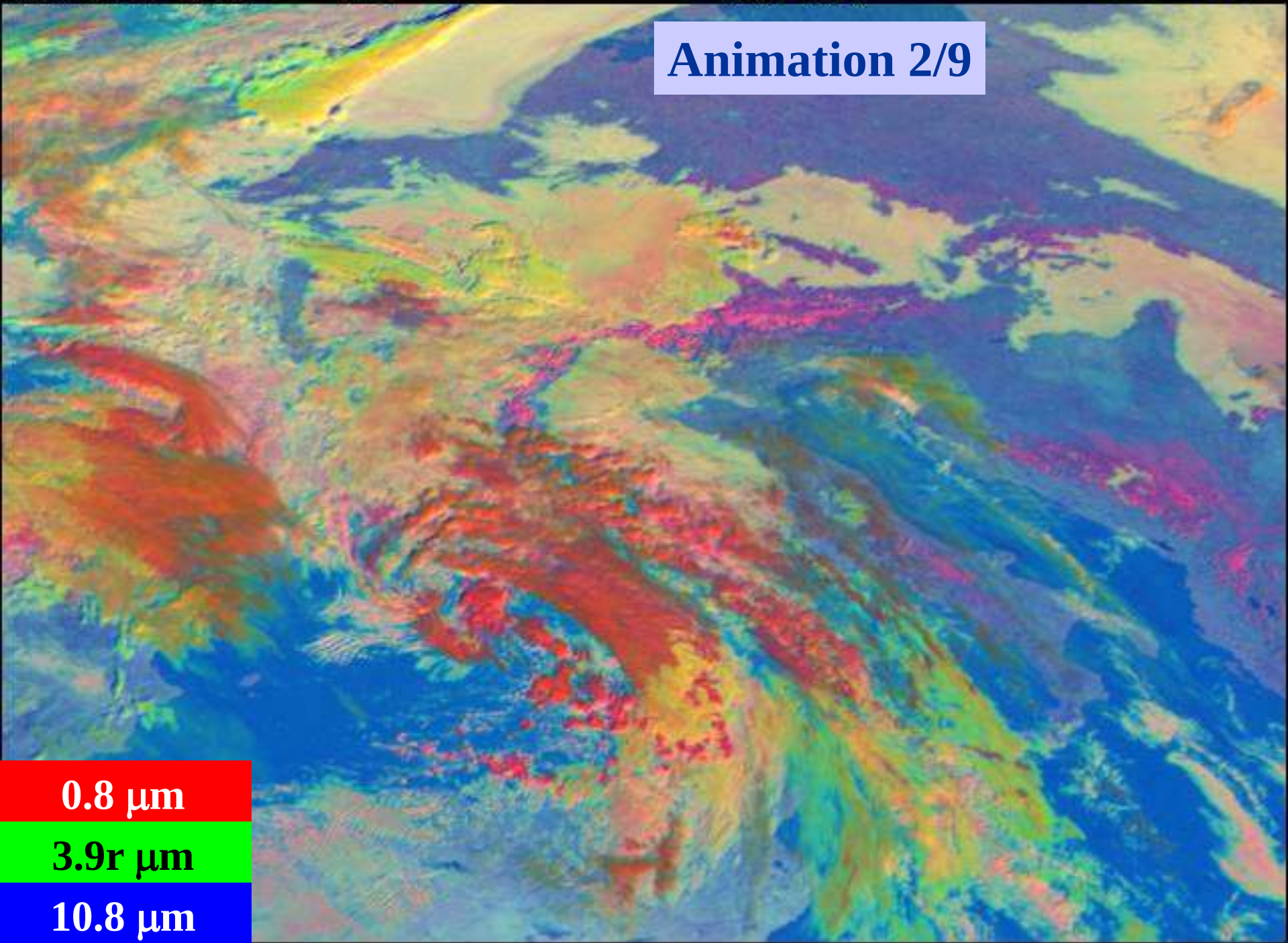
2003/12/19 10:42

CH02 0.8

CH04 A3.9

CH09 10.8

Animation 2/9



0.8 μm

3.9 μm

10.8 μm

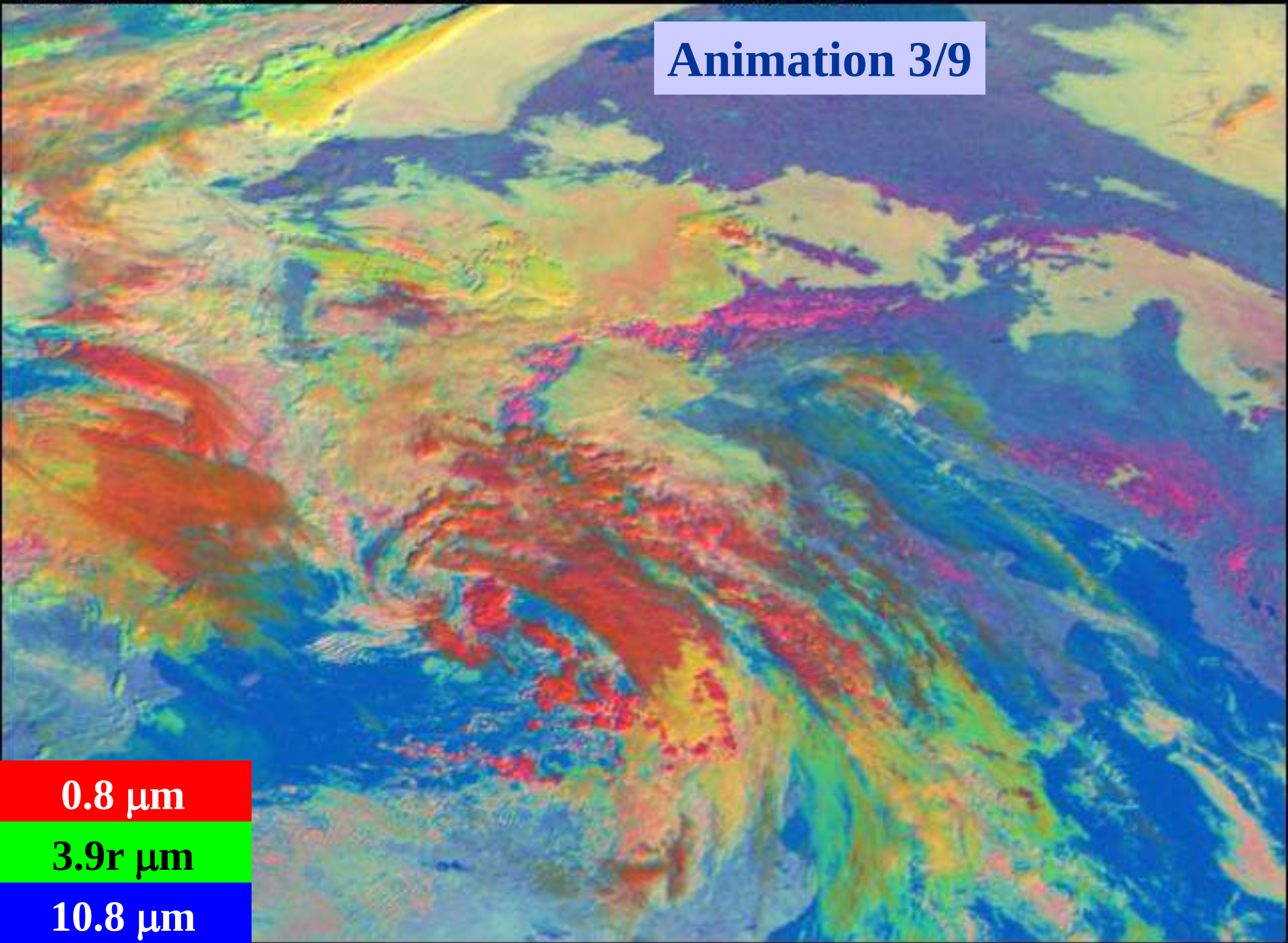
2003/12/19 10:57

CH02 0.8

CH04 A3.9

CH09 10.8

Animation 3/9



0.8 μm

3.9 μm

10.8 μm

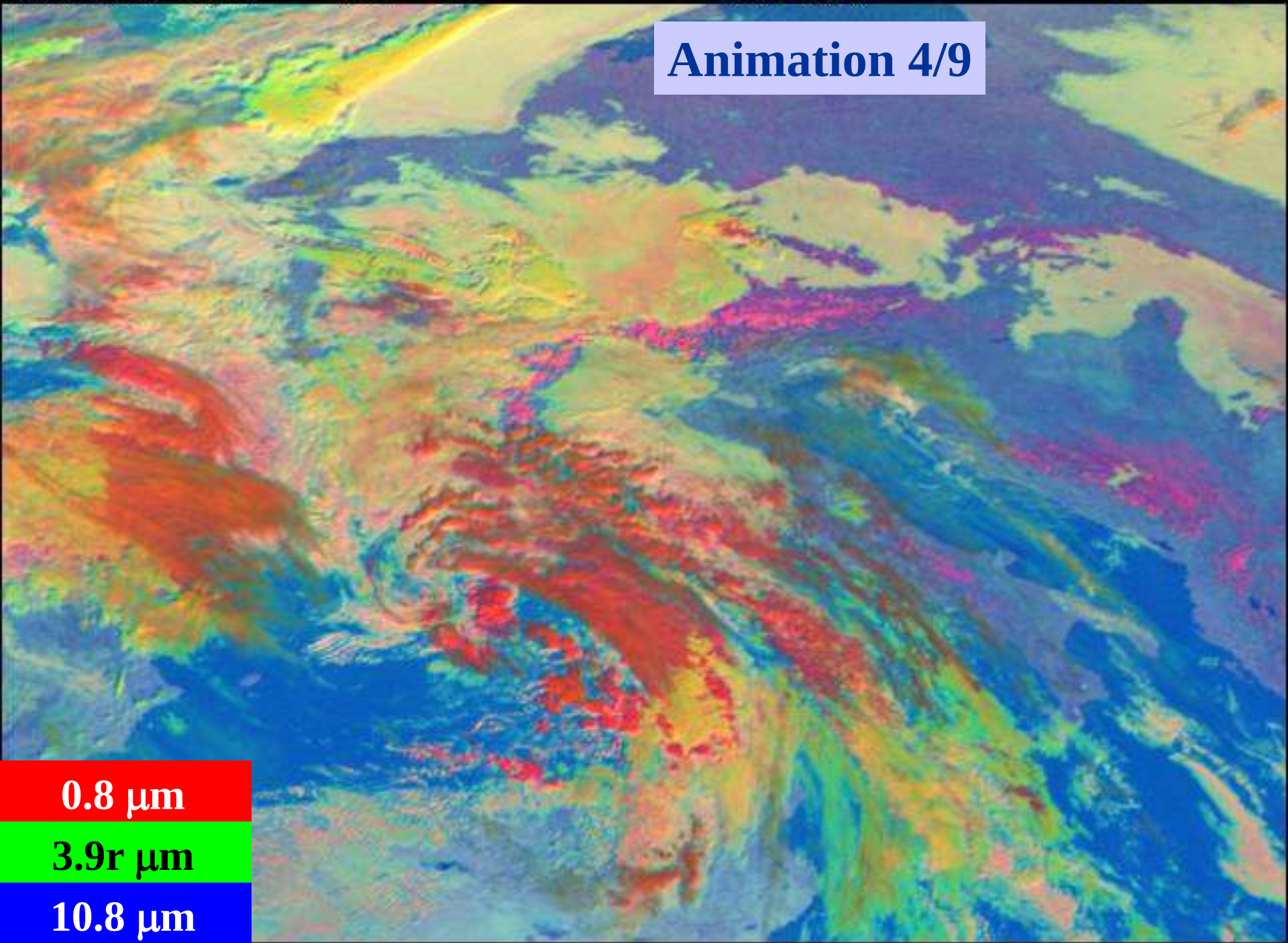
2003/12/19 11:12

CH02 0.8

CH04 A3.9

CH09 10.8

Animation 4/9



0.8 μm

3.9 μm

10.8 μm

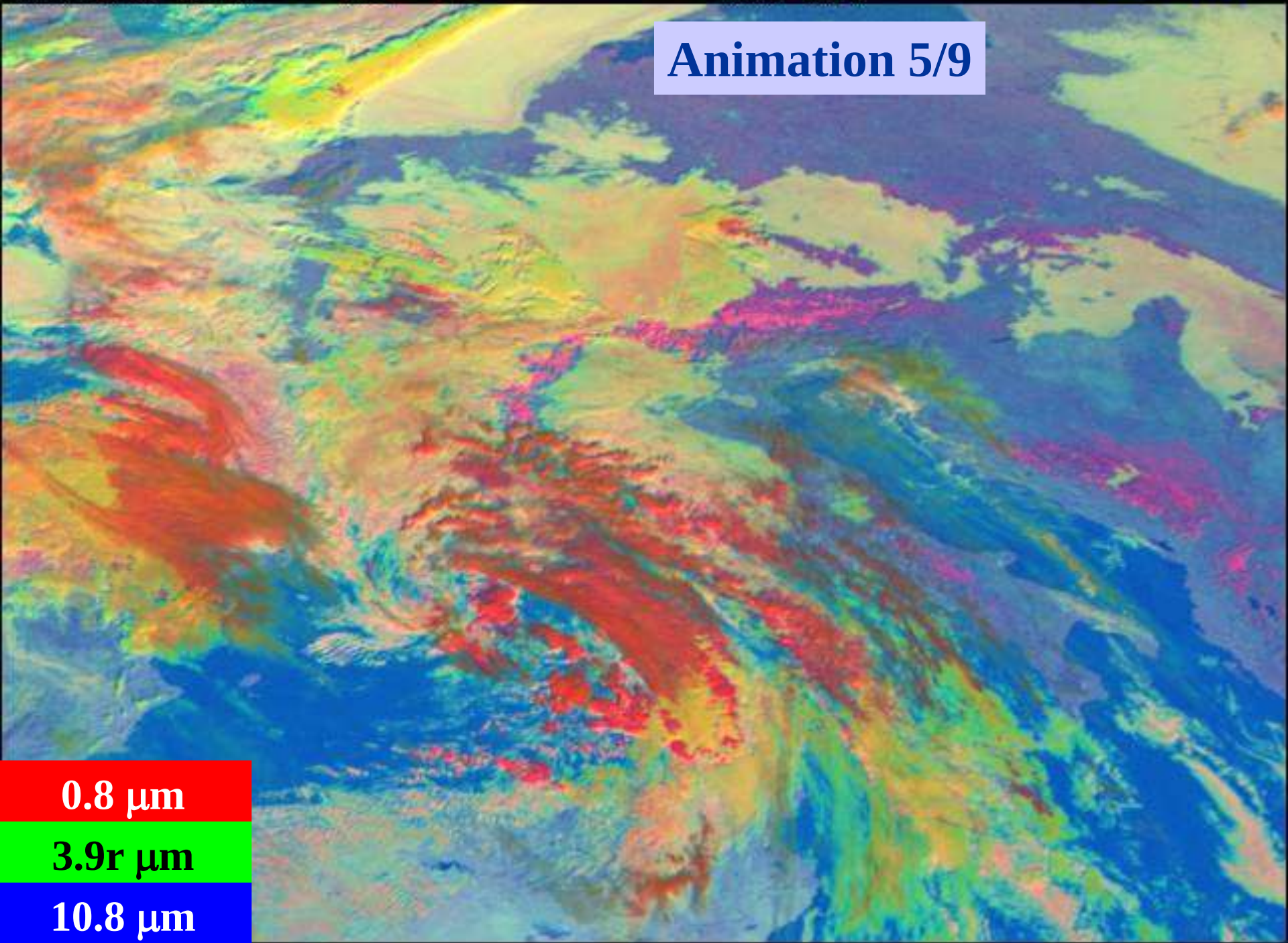
2003/12/19 11:27

CH02 0.8

CH04 A3.9

CH09 10.8

Animation 5/9



0.8 μm

3.9 μm

10.8 μm

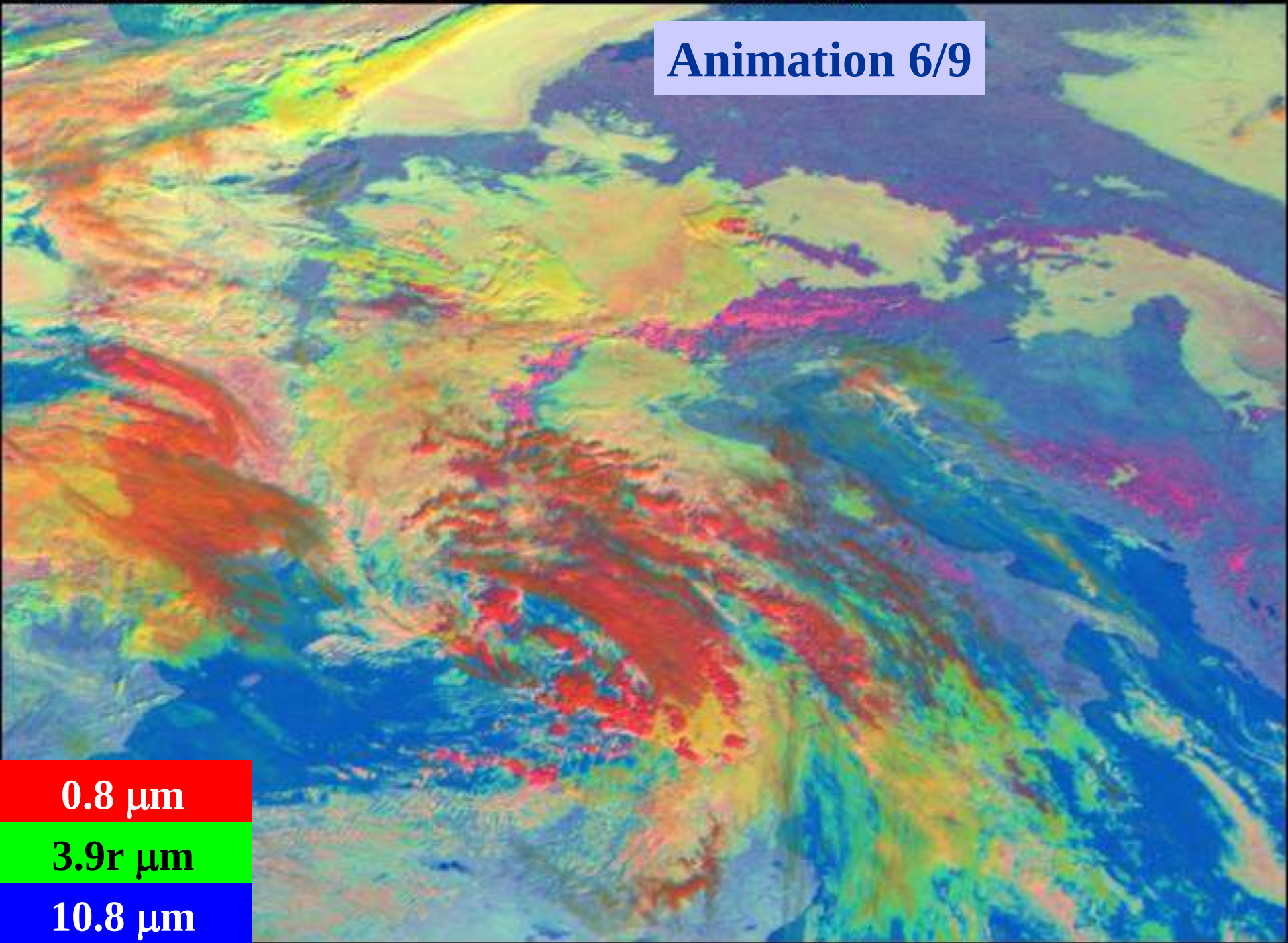
2003/12/19 11:42

CH02 0.8

CH04 A3.9

CH09 10.8

Animation 6/9



0.8 μm

3.9 μm

10.8 μm

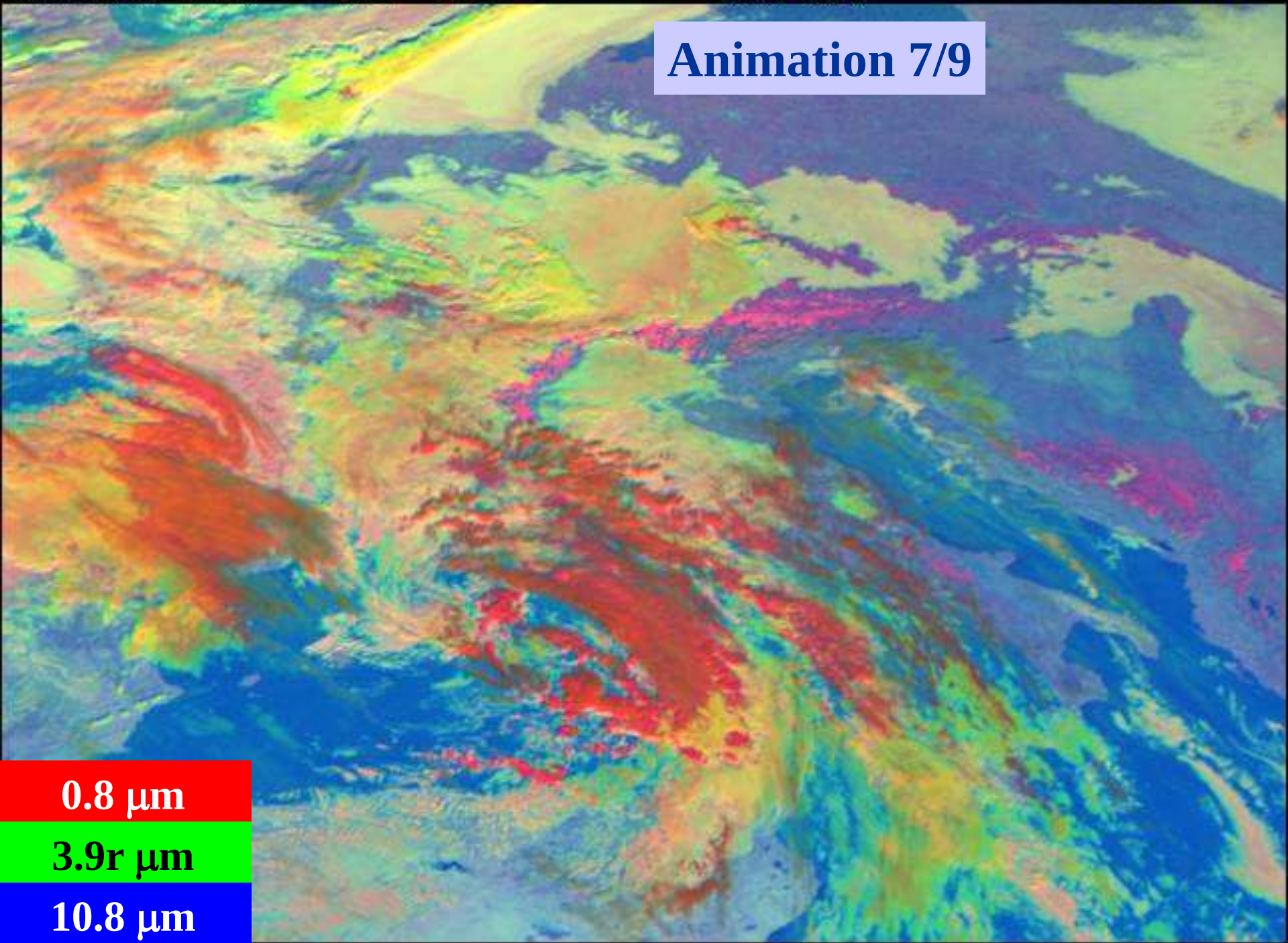
2003/12/19 11:57

CH02 0.8

CH04 A3.9

CH09 10.8

Animation 7/9



0.8 μm

3.9 μm

10.8 μm

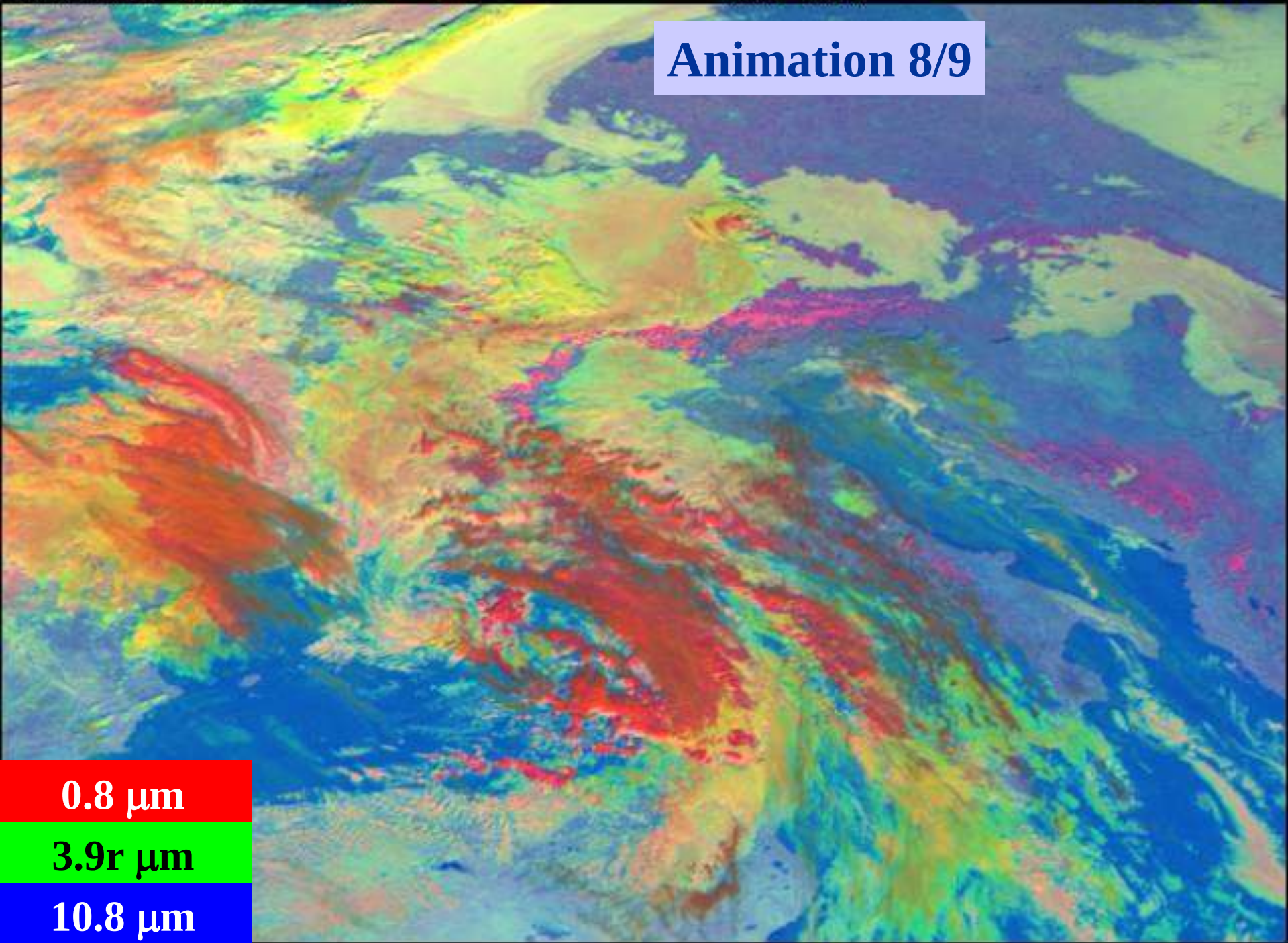
2003/12/19 12:12

CH02 0.8

CH04 A3.9

CH09 10.8

Animation 8/9



0.8 μm
3.9 μm
10.8 μm

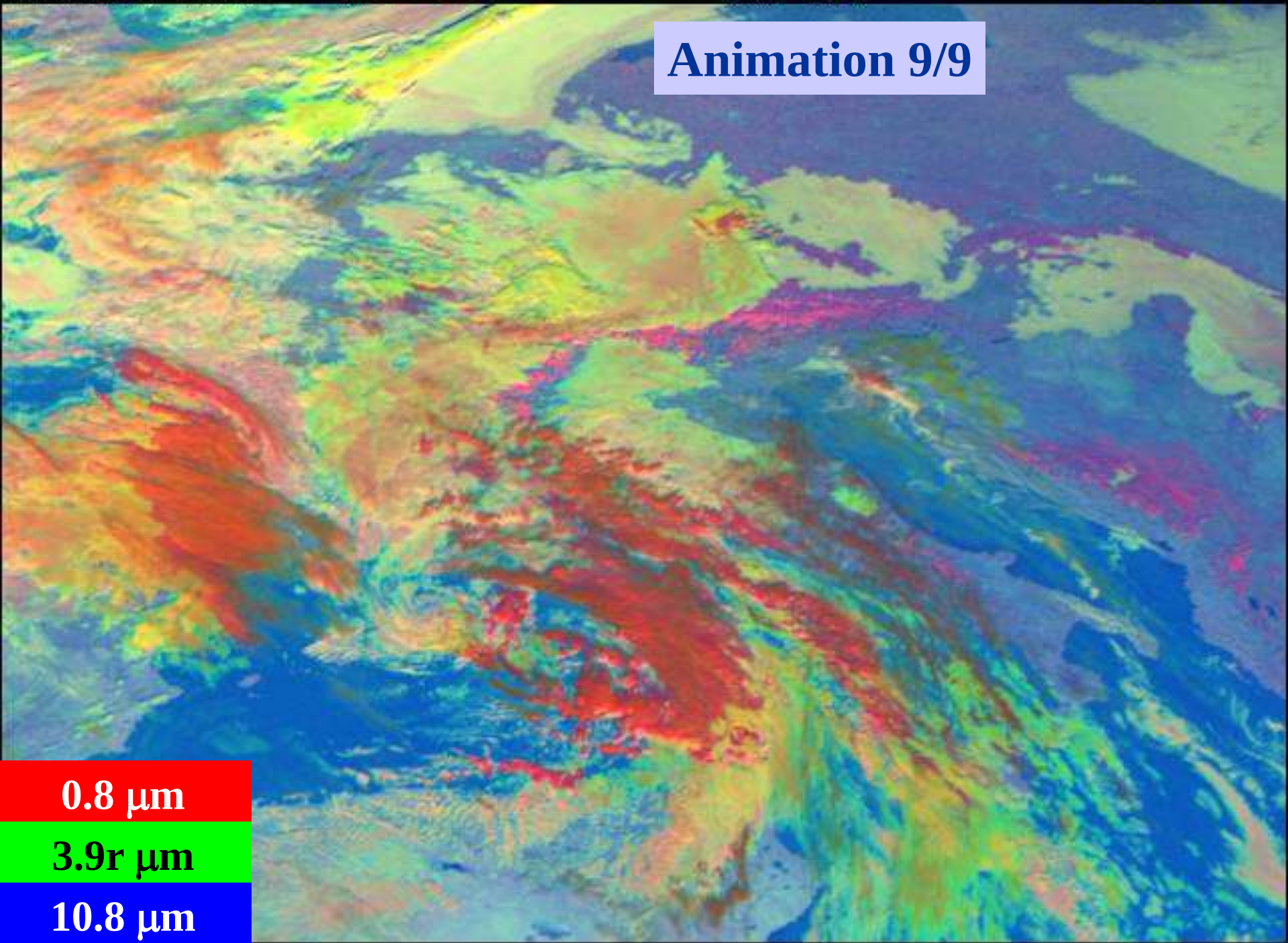
2003/12/19 12:27

CH02 0.8

CH04 A3.9

CH09 10.8

Animation 9/9



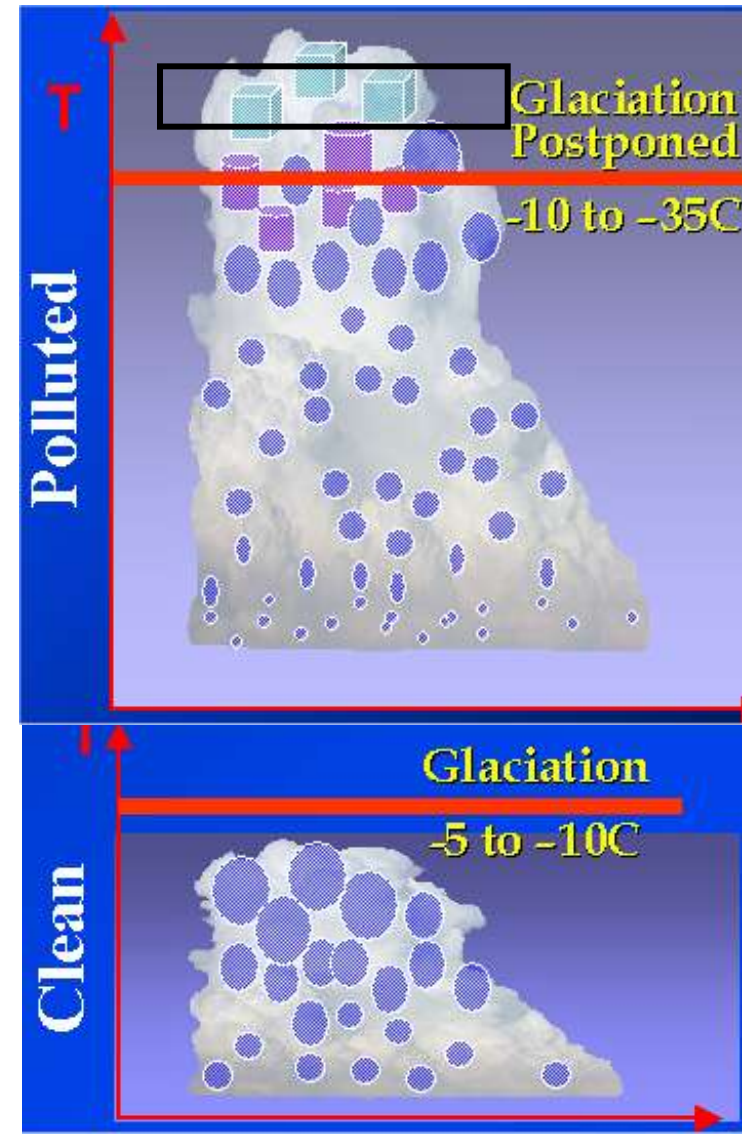
0.8 μm

3.9 μm

10.8 μm

Q: What color would be a top of a CB with large ice crystals?

-  1. **Temperature, lower for higher tops;**
-  2. **Visible brightness, reflecting more solar radiation for thicker clouds with more water and ice;**
-  3. **Cloud particle size and phase (water or ice), having larger drops for clouds with greater depth. Drops appear larger when freezing at temperatures that can range between 0 and -38°C.**

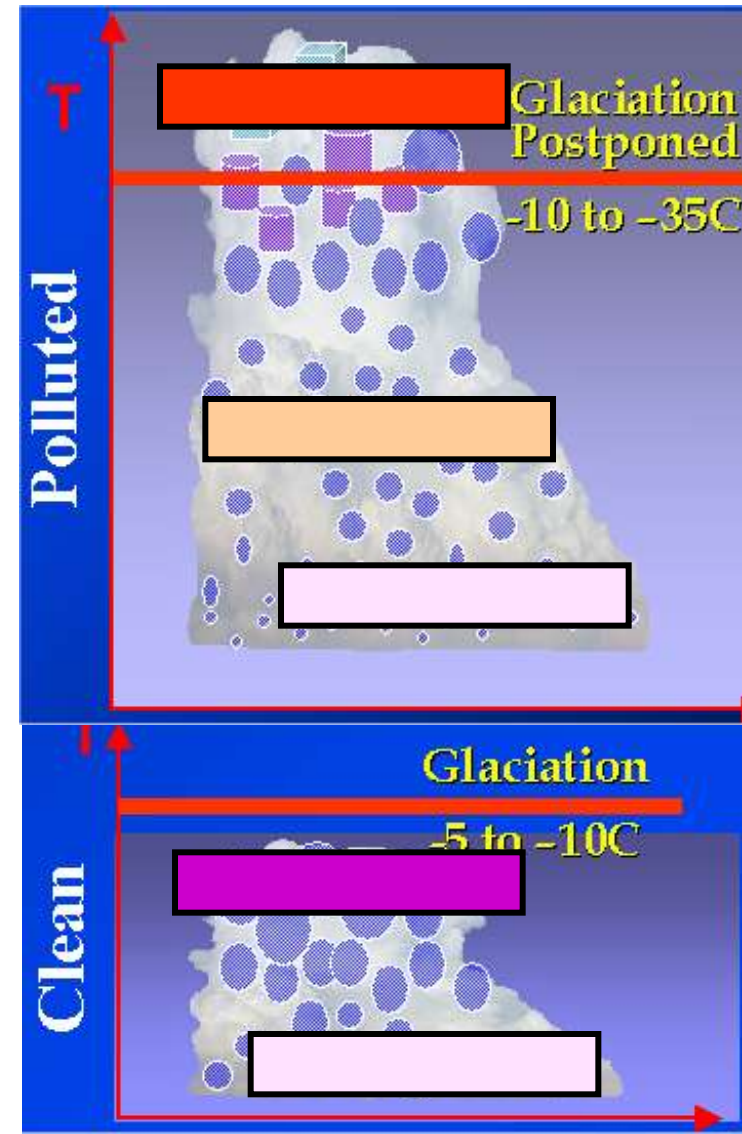


Q: What color would be a top of a CB with large ice crystals?
A: Low T + Visibly Bright + Large Ice =

1. Temperature, lower for higher tops;

2. Visible brightness, reflecting more solar radiation for thicker clouds with more water and ice;

3. Cloud particle size and phase (water or ice), having larger drops for clouds with greater depth. Drops appear larger when freezing at temperatures that can range between 0 and -38°C.



Composition of thunderstorm clouds

Ice



High red. Visible bright cloud: Large $0.6\text{ }\mu\text{m}$ reflectance
Low green. Large ice particles: Small 1.6 or $3.9\text{ }\mu\text{m}$ reflectance
Low blue. Cold. Low $10.8\text{ }\mu\text{m}$ temperature.

Mixed phase



High red. Visible bright cloud: Large $0.6\text{ }\mu\text{m}$ reflectance
Medium green. Mix of ice and drops: Medium 1.6 or $3.9\text{ }\mu\text{m}$ reflectance
Medium blue. Cool. Medium $10.8\text{ }\mu\text{m}$ temperature.

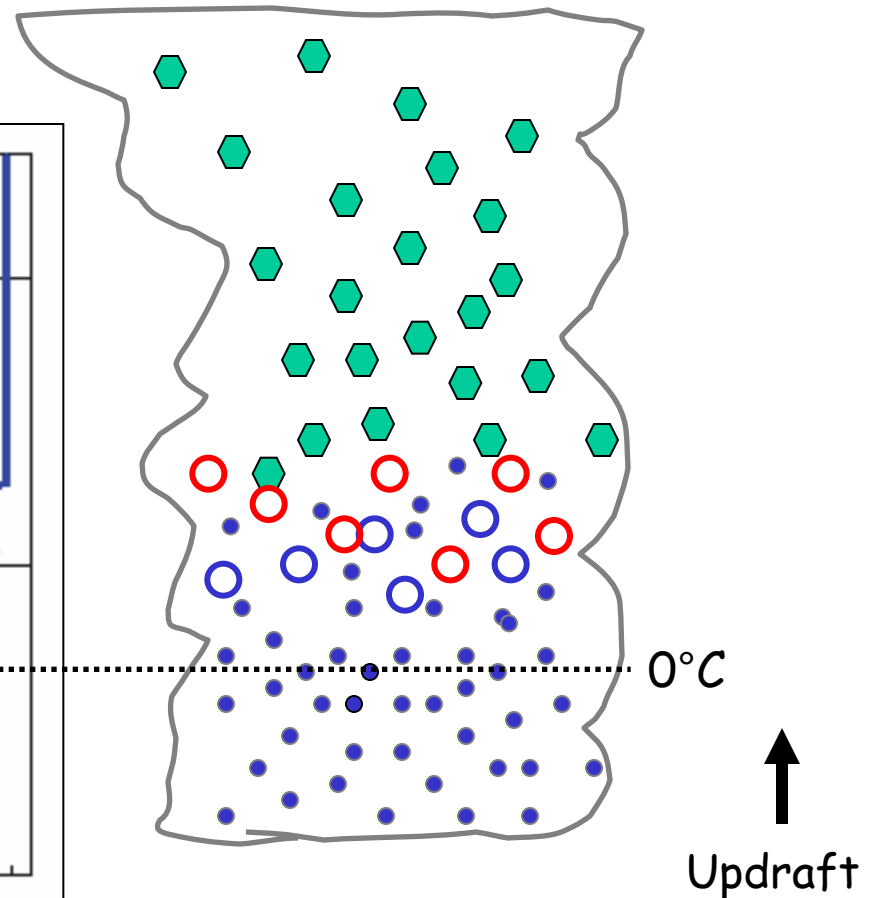
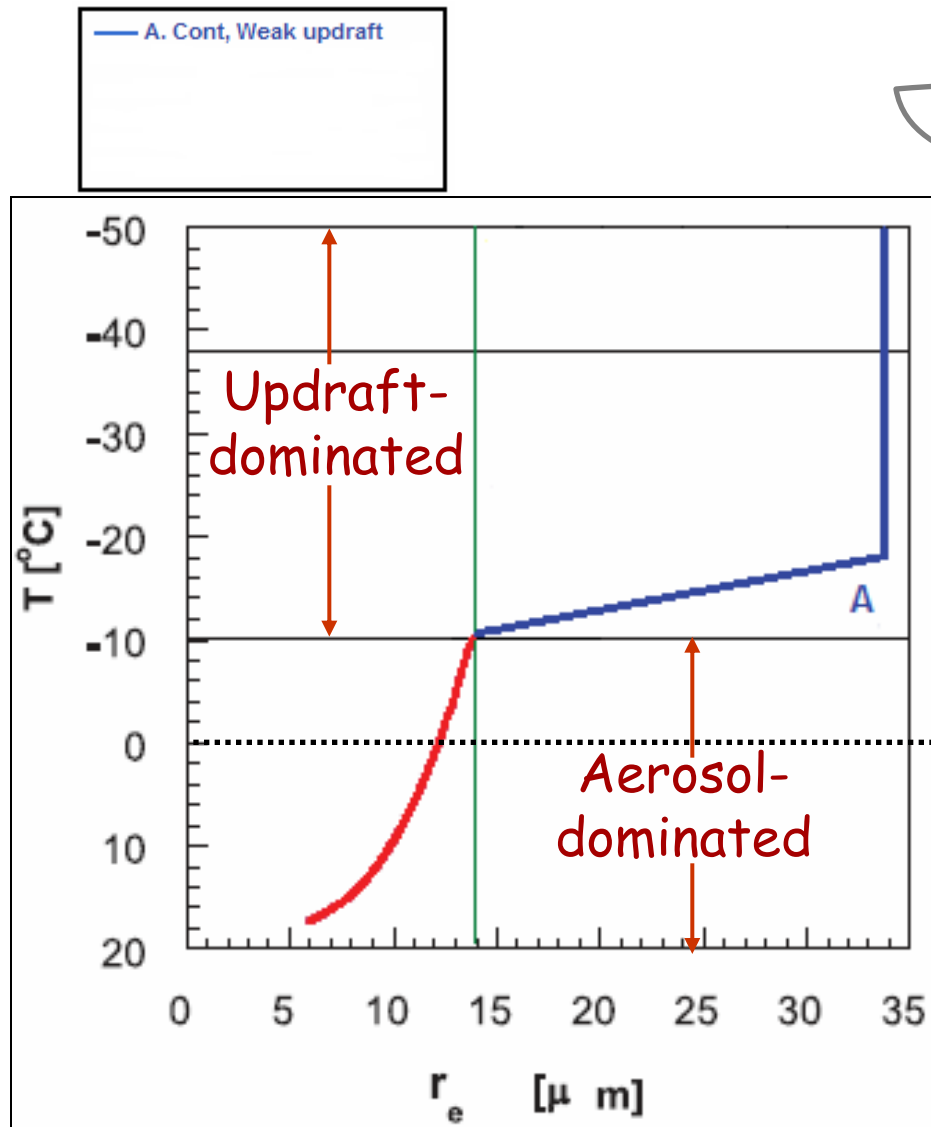
Water



High red. Visible bright cloud: Large $0.6\text{ }\mu\text{m}$ reflectance
High green. Small drops: High 1.6 or $3.9\text{ }\mu\text{m}$ reflectance
High blue. Warm. High $10.8\text{ }\mu\text{m}$ temperature.

Severe convective storms and cloud electrification

Cont, Weak updraft

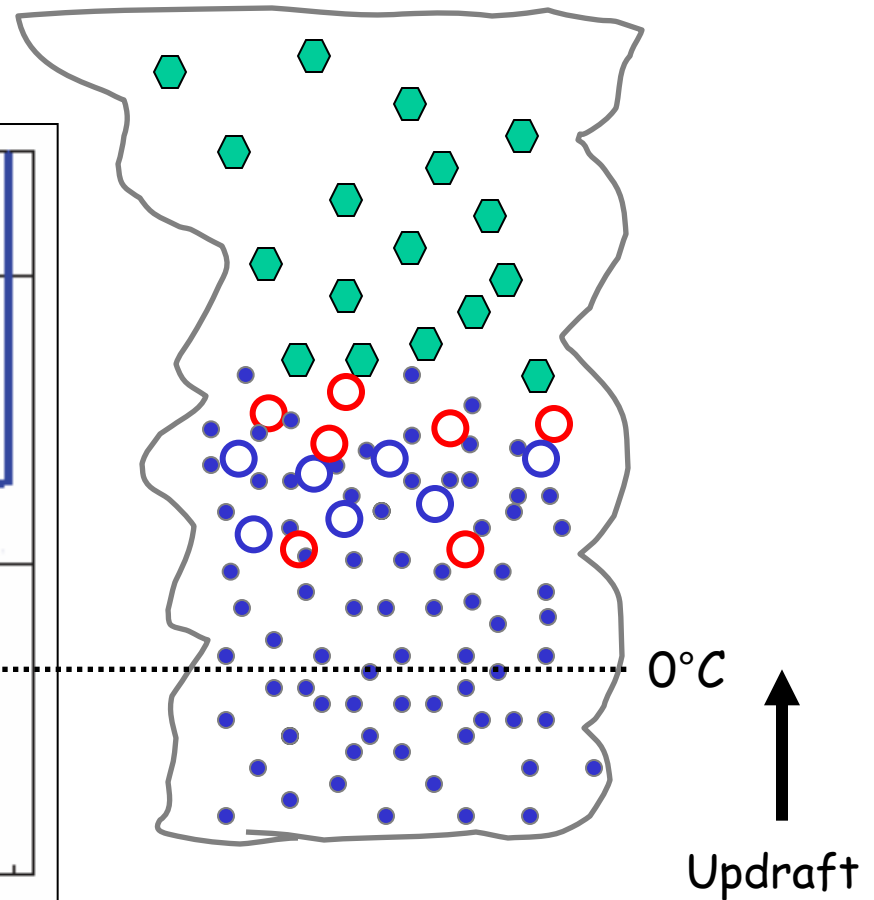
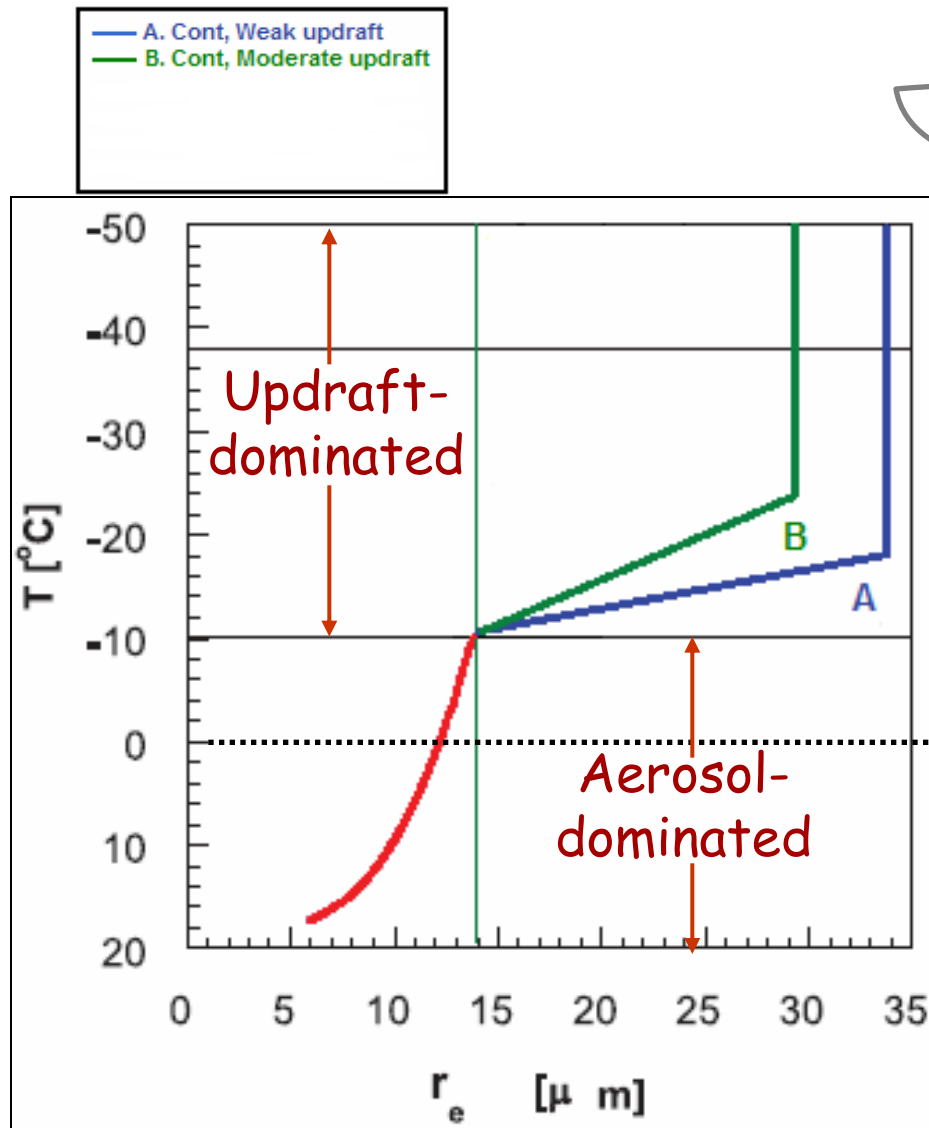


- Cloud droplets
- Rain drop
- Ice precipitation
- ⬡ Ice crystal

After: Rosenfeld et al., JAMC 2008

Severe convective storms and cloud electrification

Cont, Moderate updraft

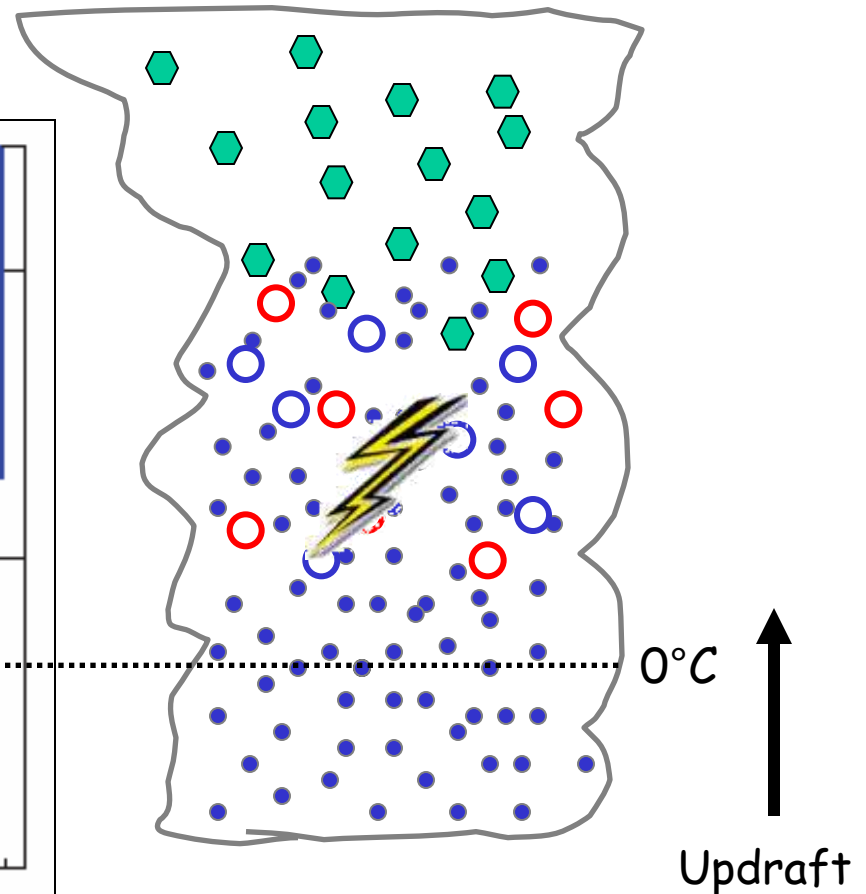
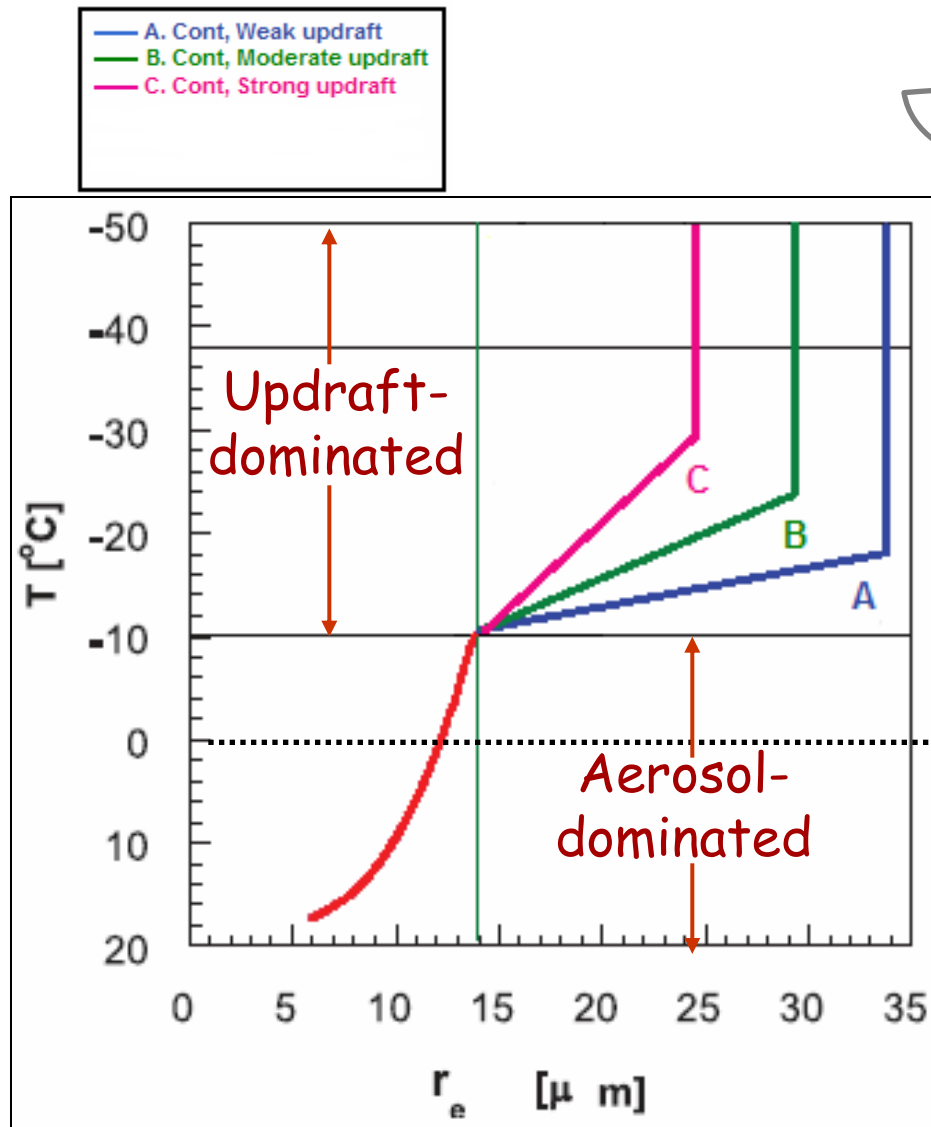


- Cloud droplets
- Rain drop
- Ice precipitation
- ⬡ Ice crystal

After: Rosenfeld et al., JAMC 2008

Severe convective storms and cloud electrification

Cont, Strong updraft

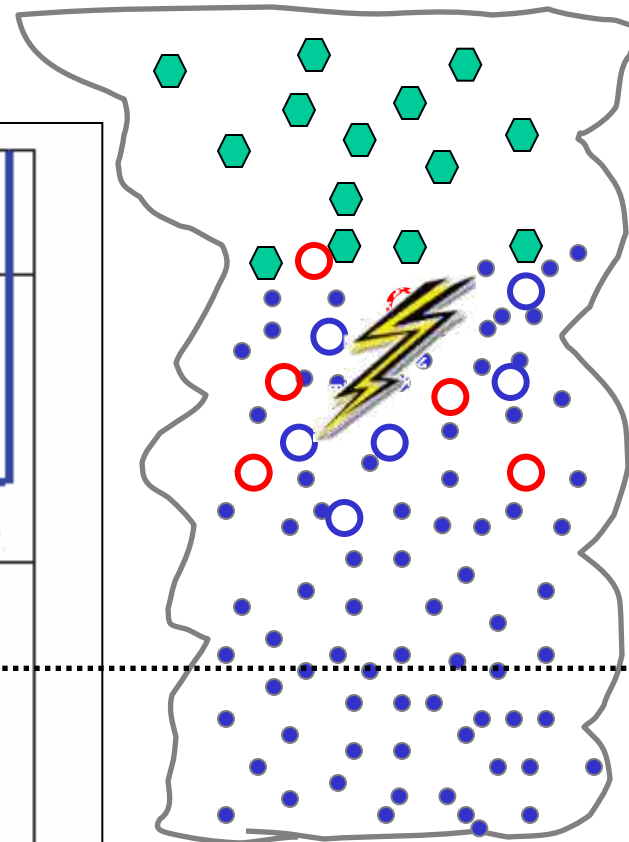
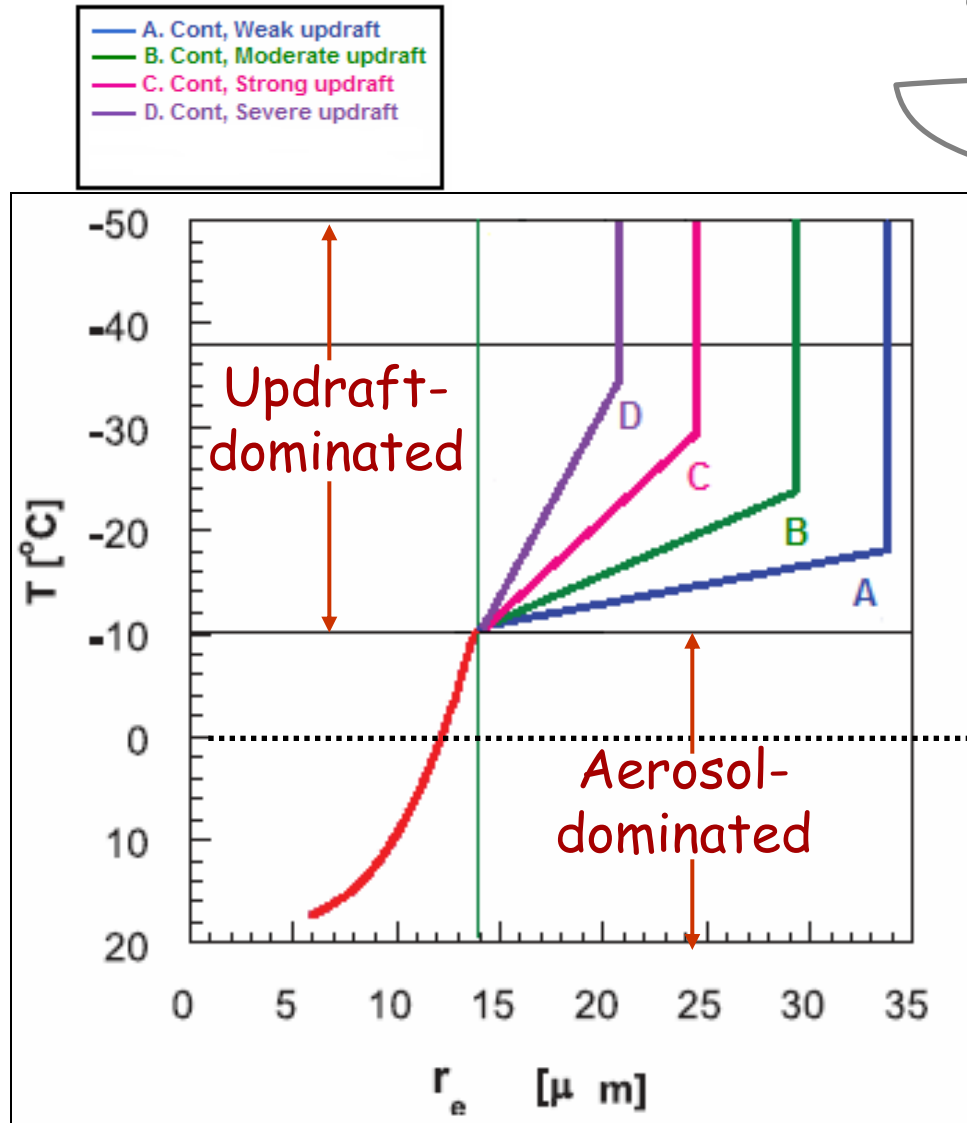


- Cloud droplets
- Rain drop
- Ice precipitation
- ⬡ Ice crystal

After: Rosenfeld et al., JAMC 2008

Severe convective storms and cloud electrification

Cont, Severe updraft

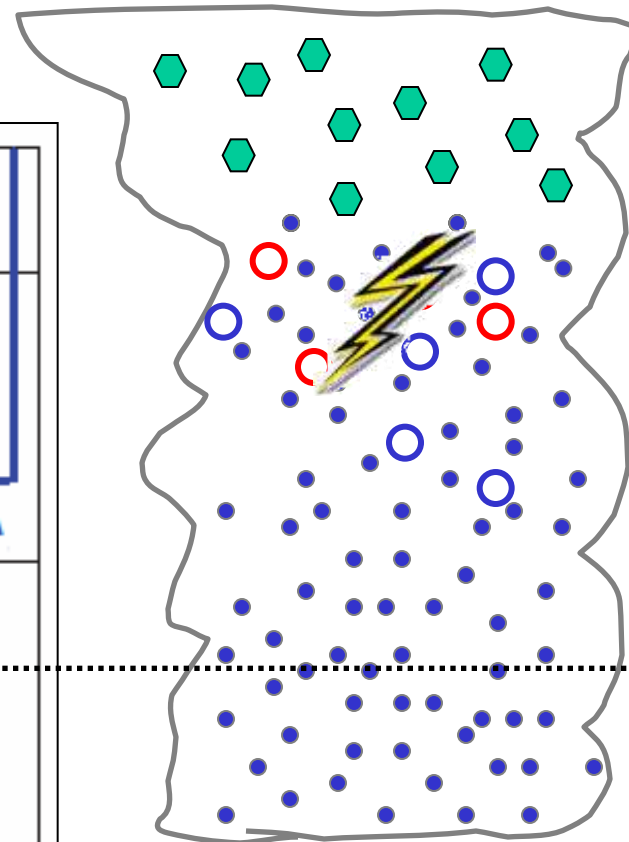
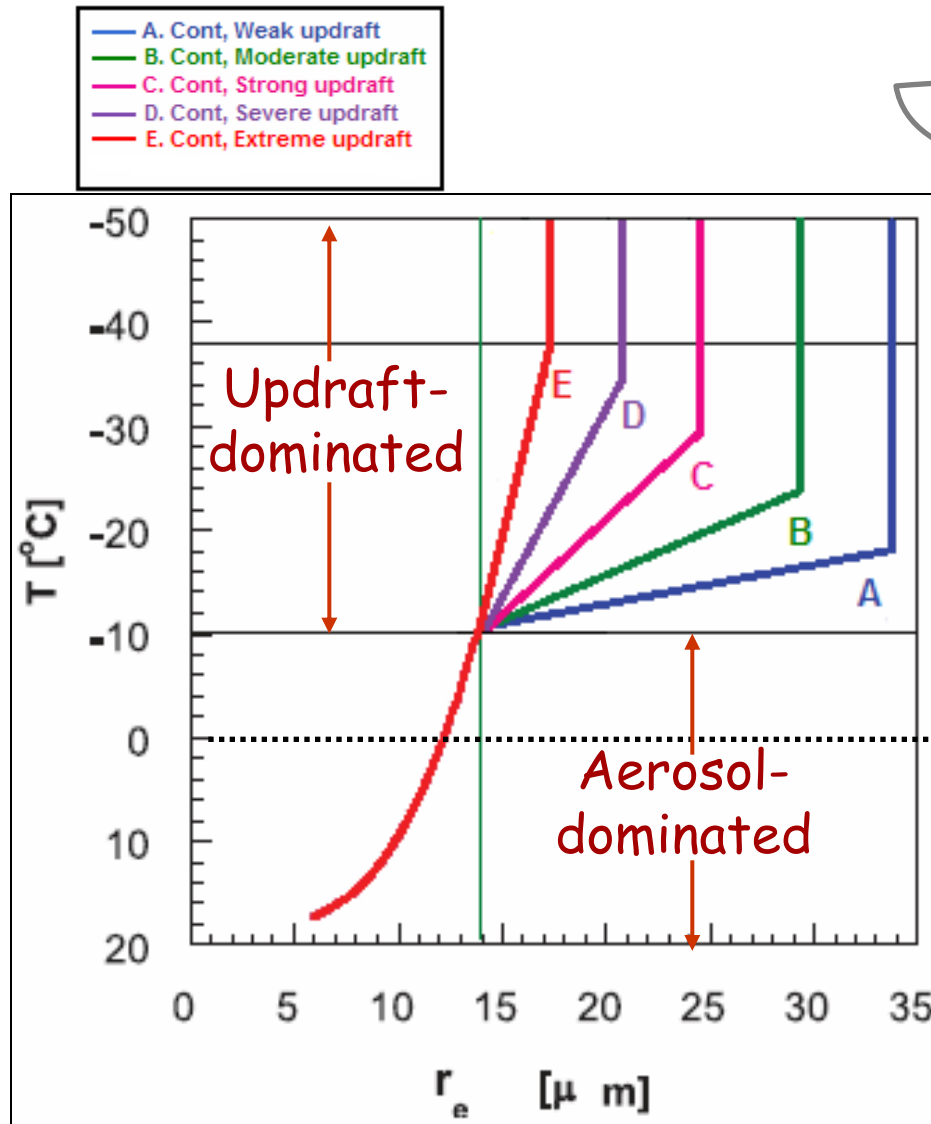


- Cloud droplets
- Rain drop
- Ice precipitation
- ⬡ Ice crystal

After: Rosenfeld et al., JAMC 2008

Severe convective storms and cloud electrification

Cont, Extreme updraft



- Cloud droplets
- Rain drop
- Ice precipitation
- ⬡ Ice crystal

After: Rosenfeld et al., JAMC 2008

Composition of severe thunderstorms

Ice



High red. Visible bright cloud: Large $0.6\ \mu\text{m}$ reflectance
Medium green. Small ice particles: Medium 1.6 or $3.9\ \mu\text{m}$ reflectance
Low blue. Cold. Low $10.8\ \mu\text{m}$ temperature.

Highly supercooled water: Sever icing



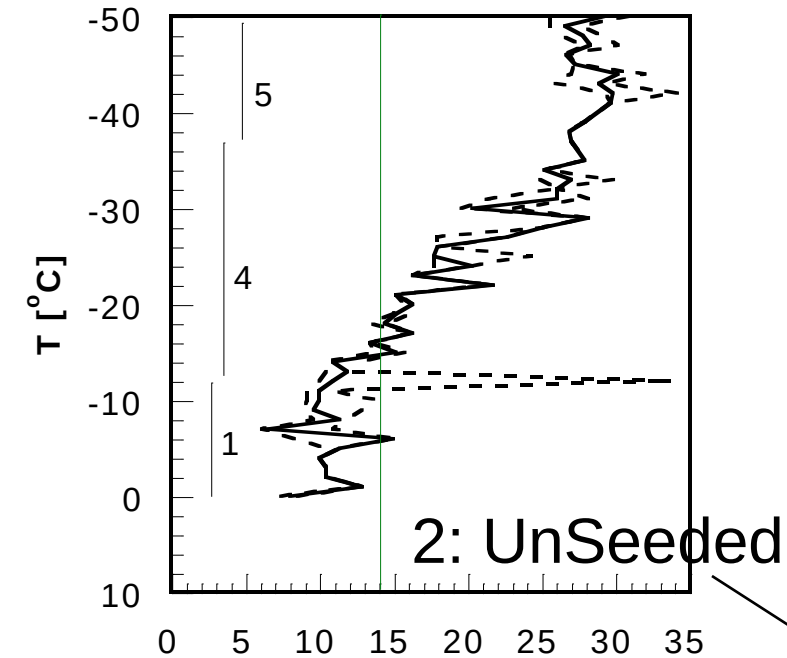
High red. Visible bright cloud: Large $0.6\ \mu\text{m}$ reflectance
High green. Small water drops: High 1.6 or $3.9\ \mu\text{m}$ reflectance
Medium blue. Cool. Medium $10.8\ \mu\text{m}$ temperature.

Water

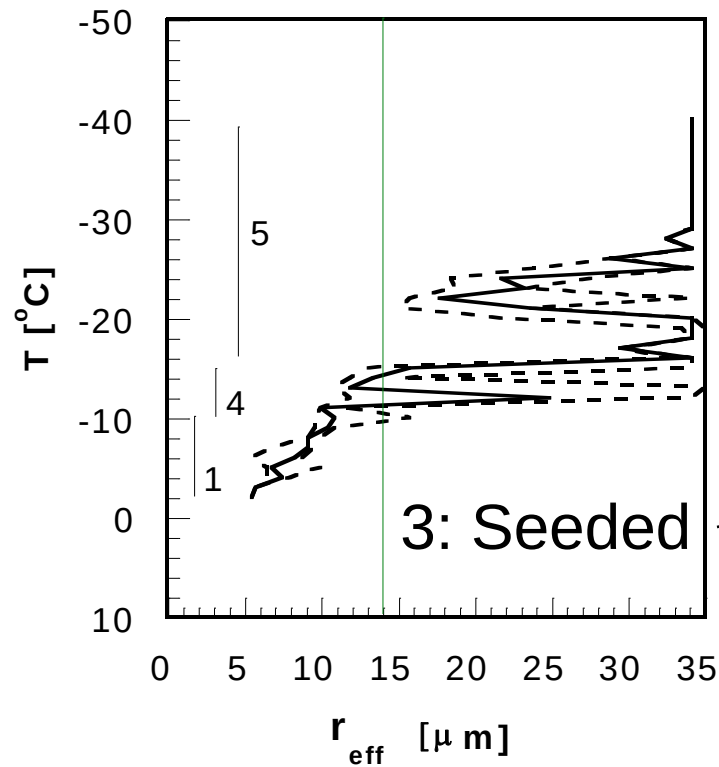


High red. Visible bright cloud: Large $0.6\ \mu\text{m}$ reflectance
High green. Small water drops: High 1.6 or $3.9\ \mu\text{m}$ reflectance
High blue. Warm. High $10.8\ \mu\text{m}$ temperature.

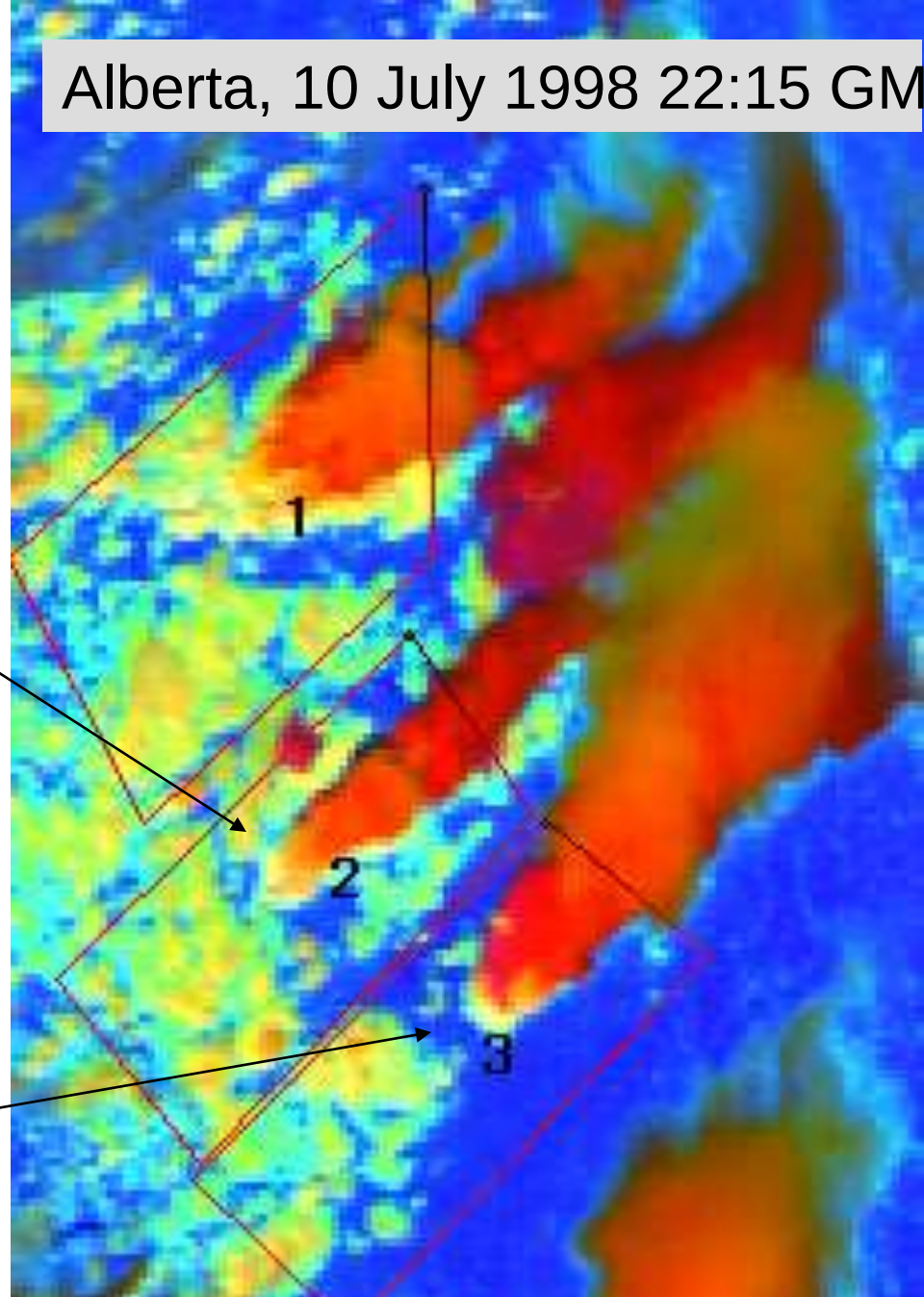
Alberta, 10 July 1998 22:15 GM



2: UnSeeded



3: Seeded



Animation 1/3

1. Large warm ice
2. Large cold ice
3. Small cold ice
4. Small cold water
5. Large warm water

The violently growing Cb cells are characterized by small particles at their tops.

Zambia & Zaire:
2003 09 07 11:57

0.8 μm

3.9 μm

10.8 μm

Animation 2/3

1. Large warm ice
2. Large cold ice
3. Small cold ice
4. Small cold water
5. Large warm water

The violently growing Cb cells are characterized by small particles at their tops.

Zambia & Zaire:
2003 09 07 12:12

0.8 μm

3.9 μm

10.8 μm

Animation 3/3

1. Large warm ice
2. Large cold ice
3. Small cold ice
4. Small cold water
5. Large warm water

The violently growing Cb cells are characterized by small particles at their tops.

Zambia & Zaire:
2003 09 07 12:27

0.8 μm

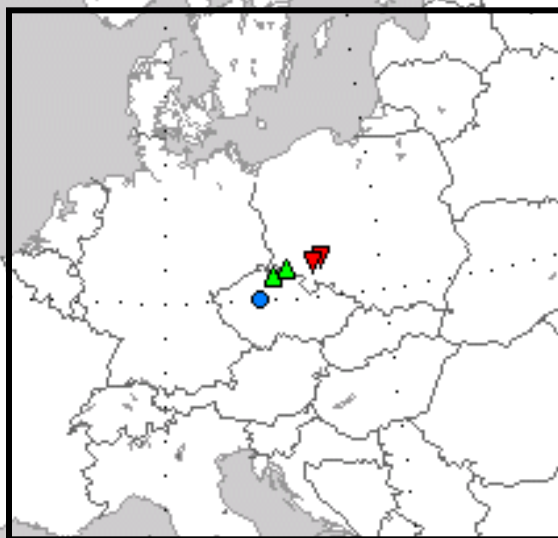
3.9 μm

10.8 μm

2011-06-14 18:50:35



European Severe
Weather Database
www.eswd.eu
(c) ESSL



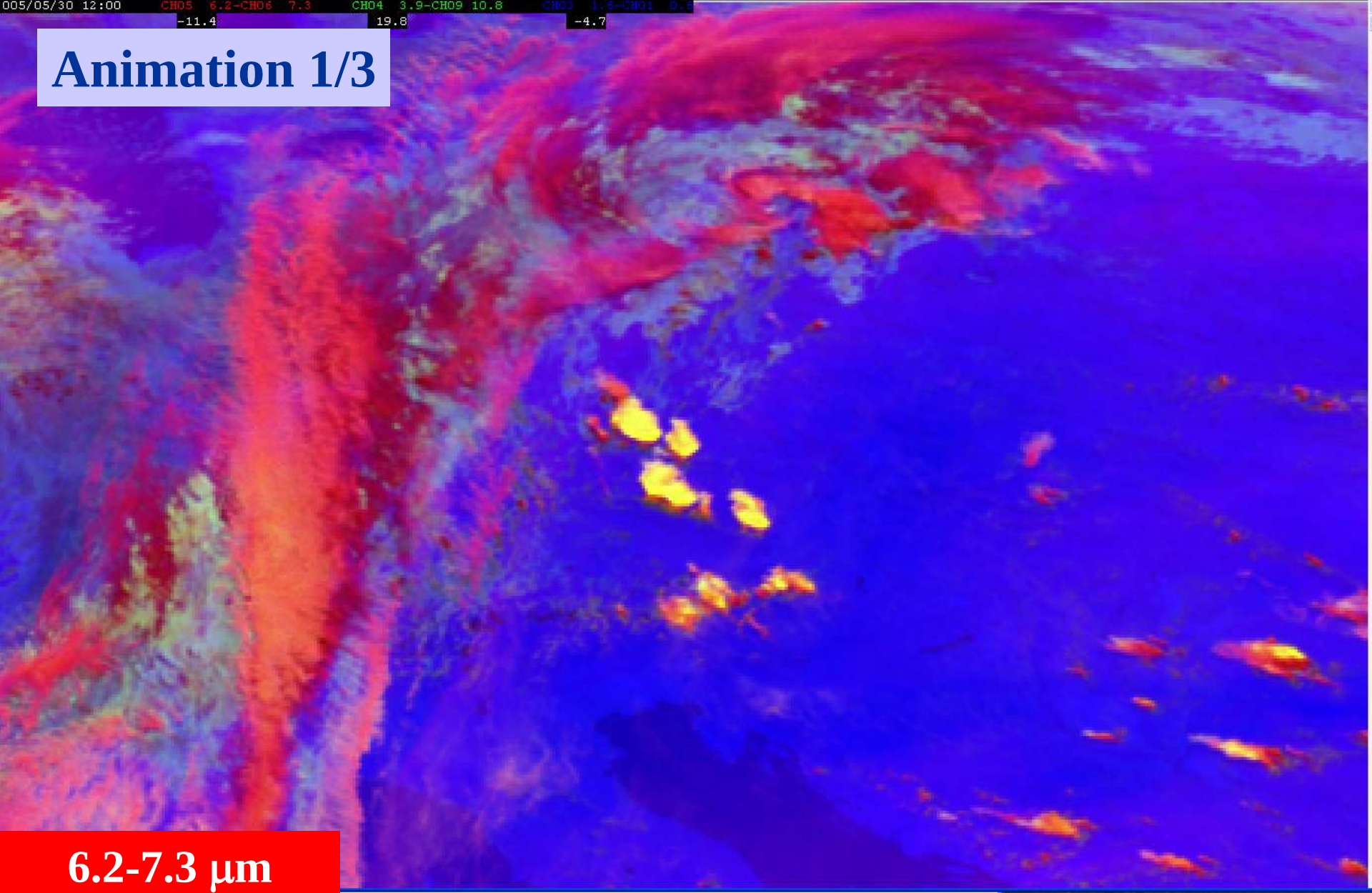
From the European Severe Weather Database, 30/5/2005 (day time).

<http://www.essl.org/ESWD/>

red: tornado, yellow: severe wind gusts, green: large hail, blue: heavy rain,
white: funnel cloud, pink: gustnado, orange: dust devil
DEFINITIONS

05/05/30 12:00 CH05 6.2-CH06 7.3 CH04 3.9-CH09 10.8 CH03 1.6-CH01 0.6
-11.4 19.8 -4.7

Animation 1/3



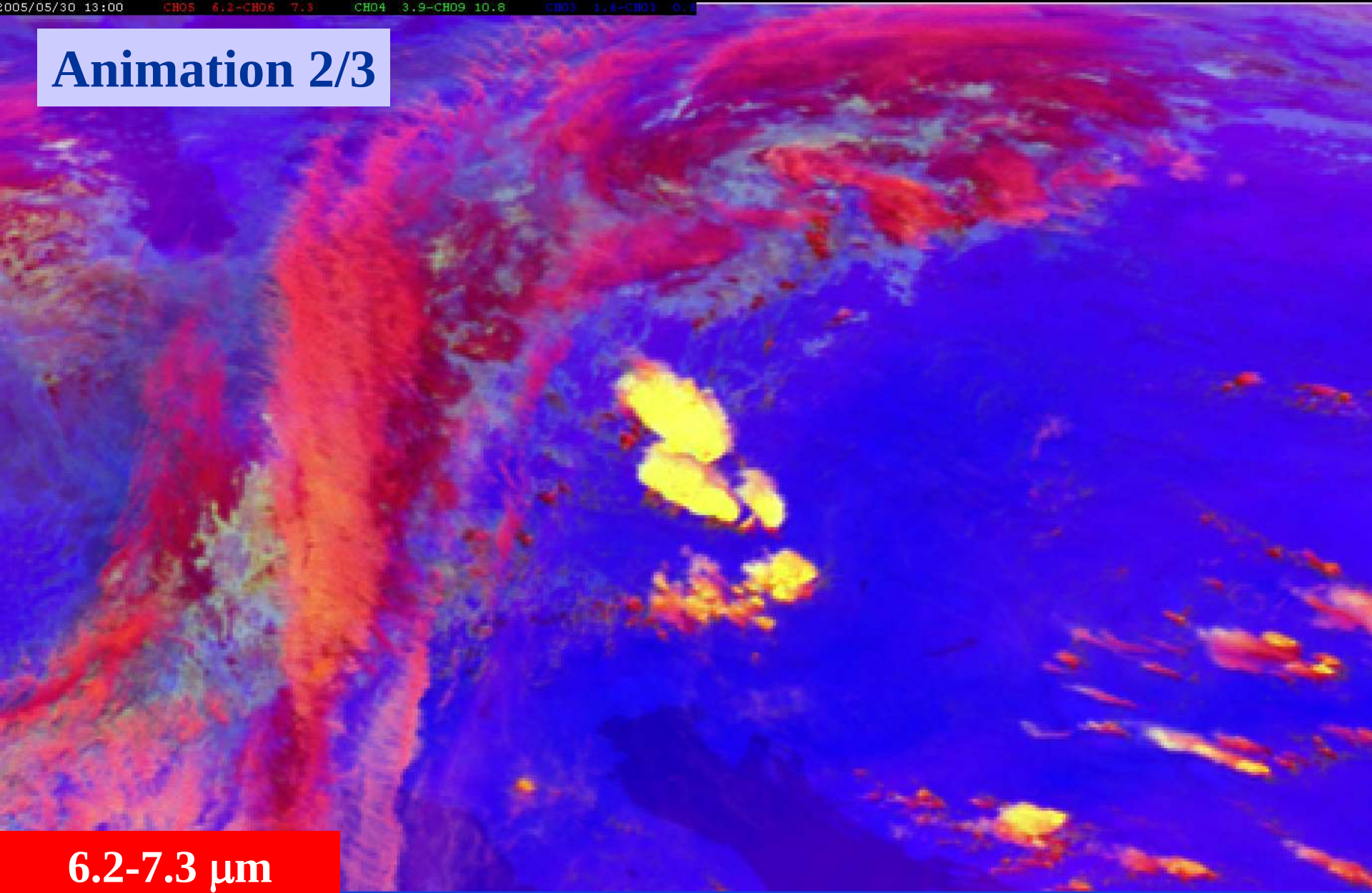
6.2-7.3 μm

3.9-10.8 μm

1.6-0.6 μm

MSG 2005 05 30 12:00

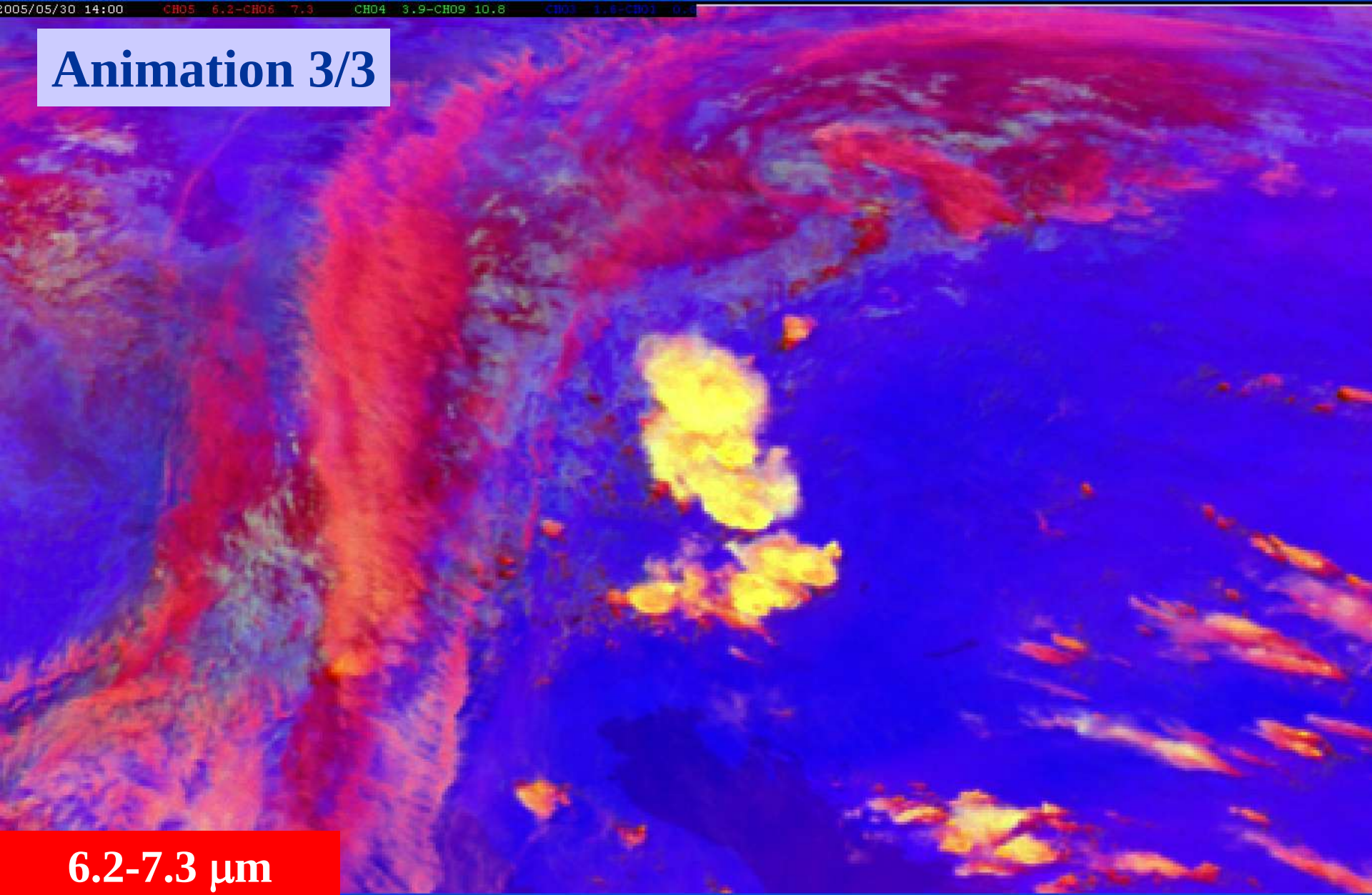
Animation 2/3



6.2-7.3 μm
3.9-10.8 μm
1.6-0.6 μm

MSG 2005 05 30 13:00

Animation 3/3



6.2-7.3 μm

3.9-10.8 μm

1.6-0.6 μm

MSG 2005 05 30 14:00

Animation 1/3

1. Large warm ice
2. Large cold ice
3. Small cold ice
4. Small cold water
5. Large warm water

Hurricane Isabel

2003 09 07 11:57

0.8 μm

3.9 μm

10.8 μm

Animation 2/3

1. Large warm ice
2. Large cold ice
3. Small cold ice
4. Small cold water
5. Large warm water

Hurricane Isabel

2003 09 07 12:12

0.8 μm

3.9 μm

10.8 μm

Animation 3/3

1. Large warm ice
2. Large cold ice
3. Small cold ice
4. Small cold water
5. Large warm water

Hurricane Isabel

2003 09 07 12:27

0.8 μm

3.9 μm

10.8 μm

NIGHT-TIME

The data rendering is done to maximize the similarity between day and night color interpretation of clouds, using **RGB** composite for the following cloud properties:

Red: Cloud depth and amount of cloud water and ice.

Day: Visible reflectance at 0.6 μm .

Night: Optical depth, approximated by 12.0-10.8 μm channels.

Green: Cloud particle size and phase.

Day: Approximated by 3.9 μm solar reflectance component.

Night: Approximated by 10.8 – 3.9 μm brightness temperature.

Blue: Temperature is provided by 10.8 μm day and night.

MSG Ship Tracks off Namibia

NIGHT

DAY

12.0-10.8 μm

10.8-3.9 μm

10.8 μm

0.8 μm

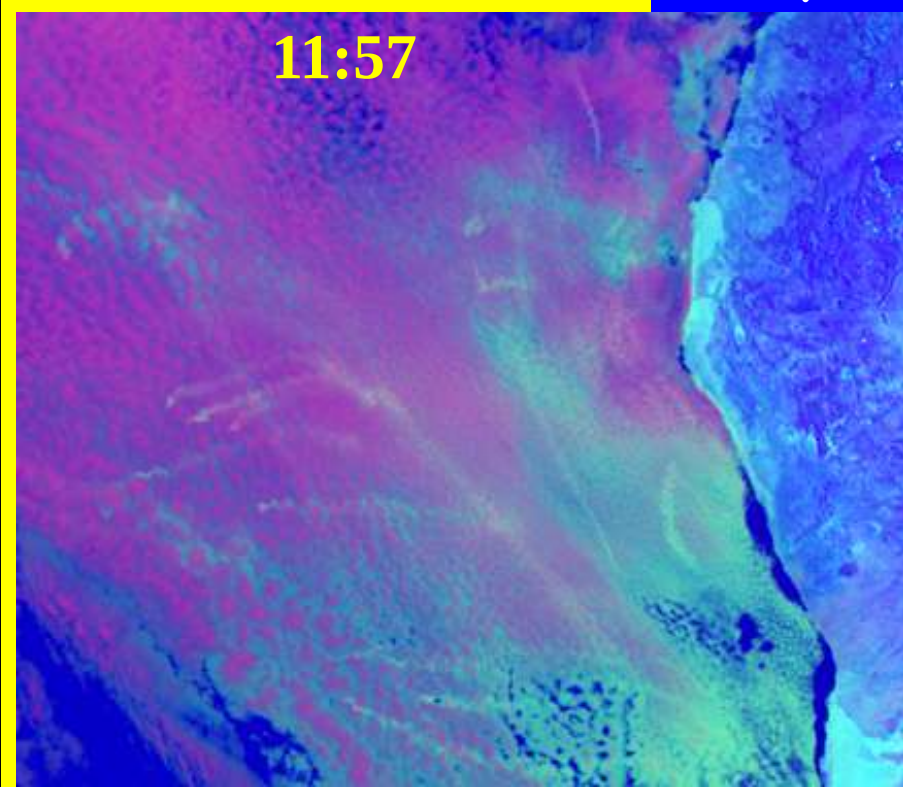
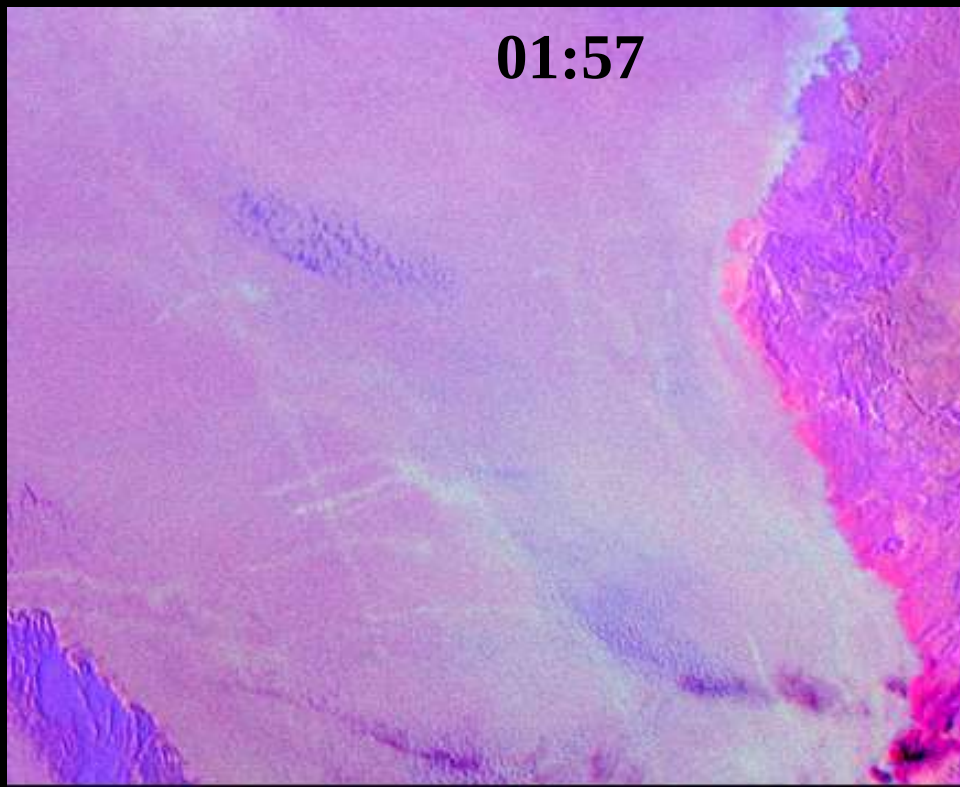
3.9 μm

10.8 μm

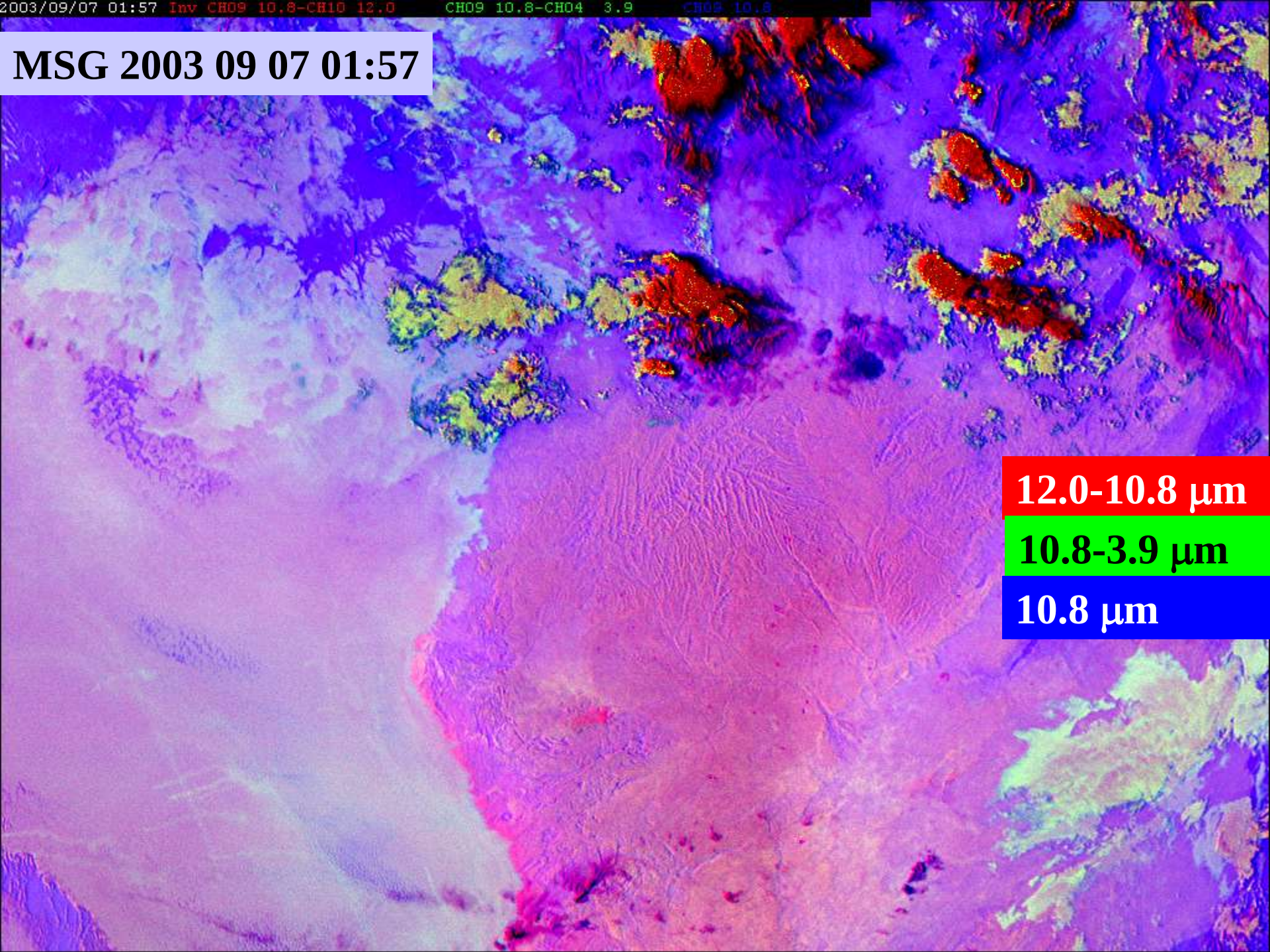
MSG 2003 09 07

01:57

11:57



MSG 2003 09 07 01:57

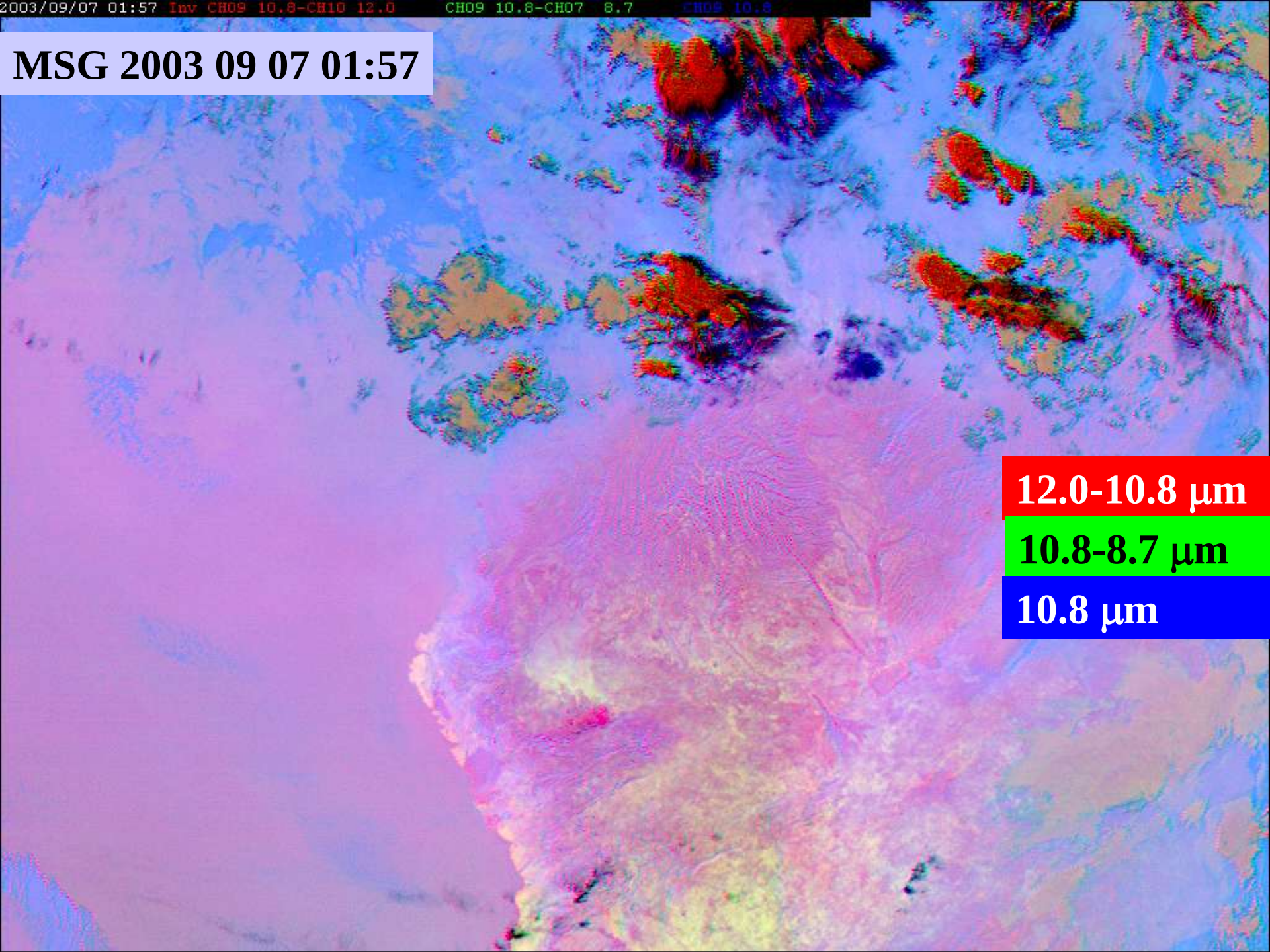


12.0-10.8 μm

10.8-3.9 μm

10.8 μm

MSG 2003 09 07 01:57

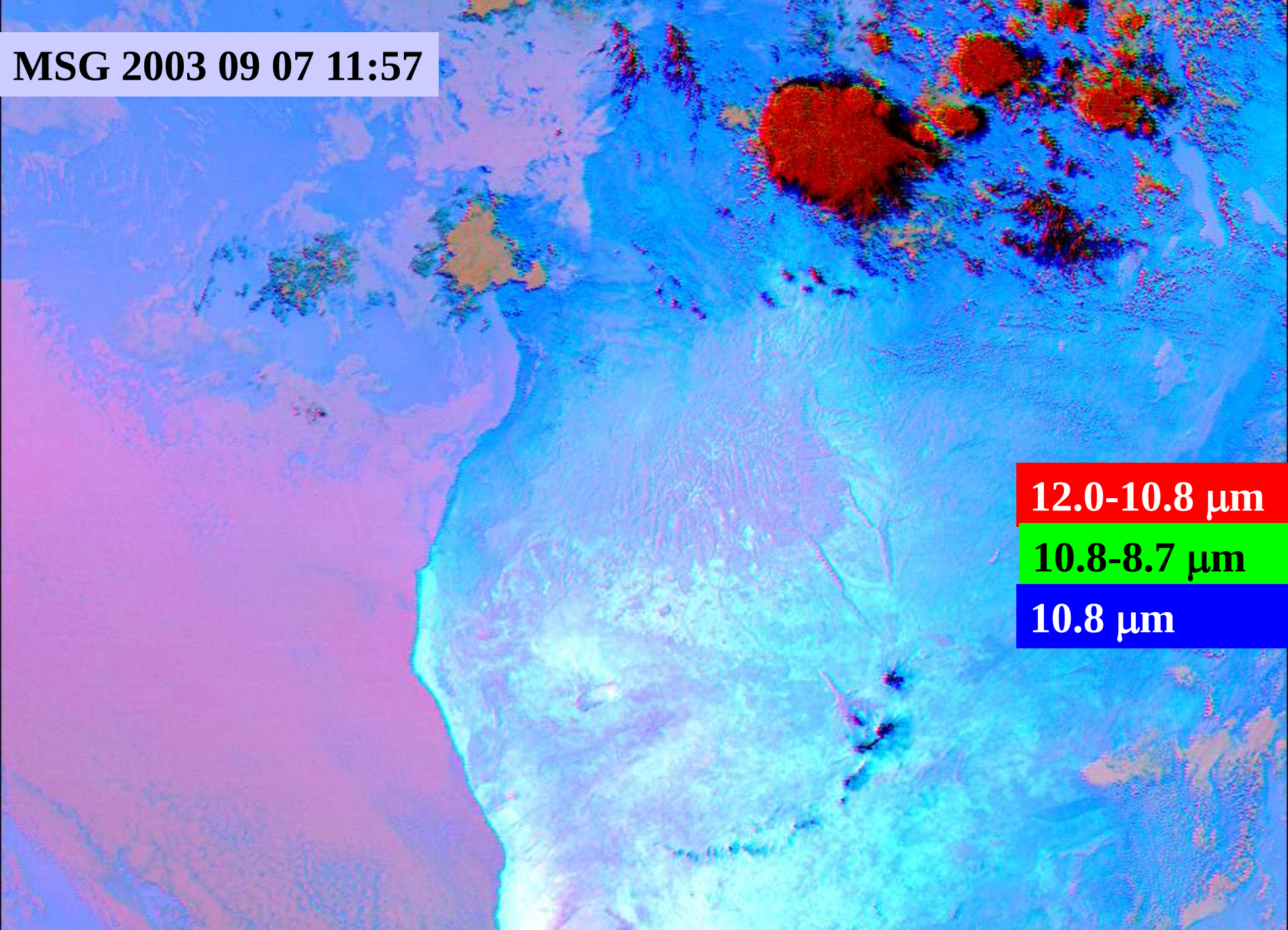


12.0-10.8 μm

10.8-8.7 μm

10.8 μm

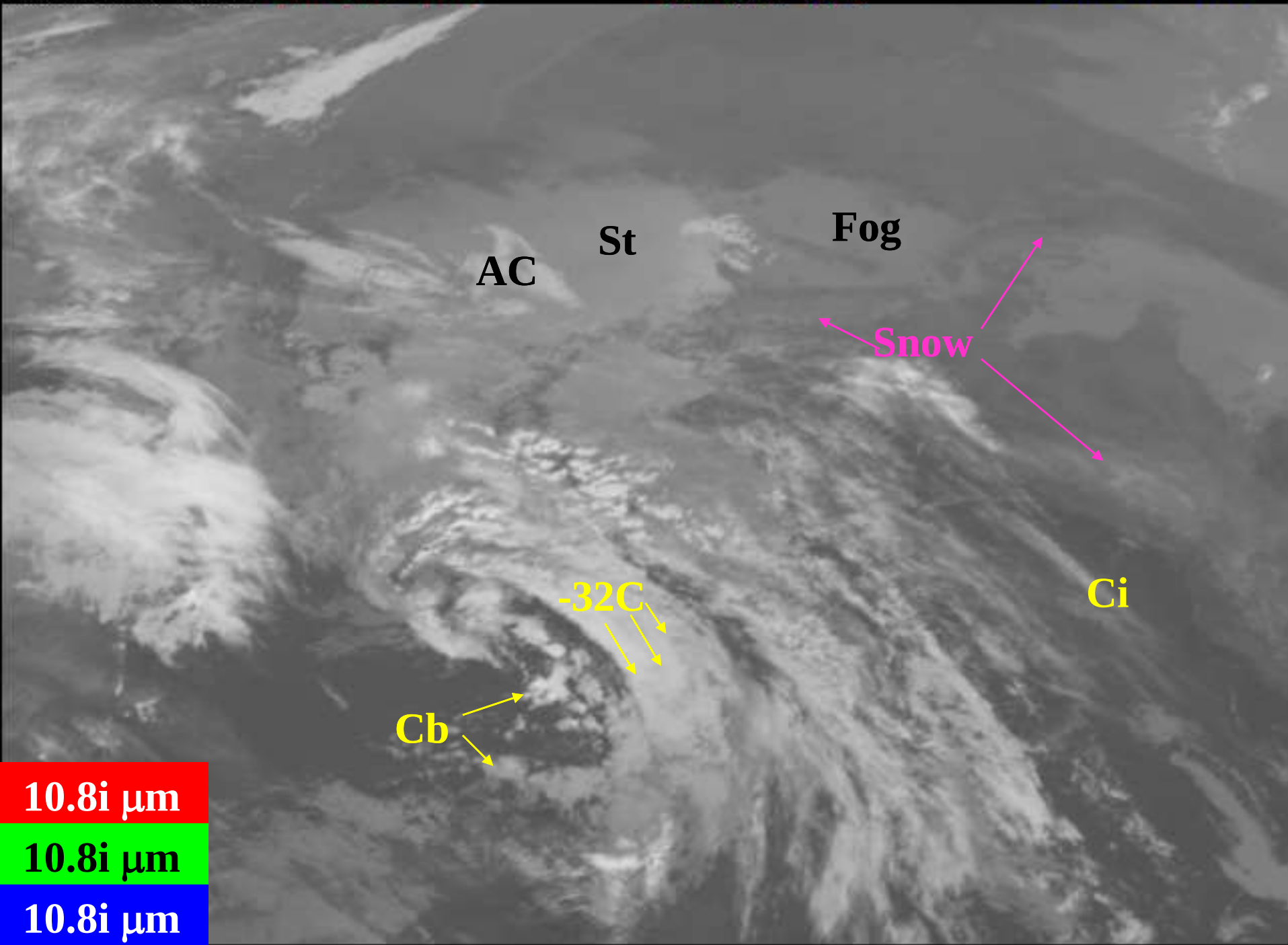
MSG 2003 09 07 11:57



12.0-10.8 μm

10.8-8.7 μm

10.8 μm



10.8i μm

10.8i μm

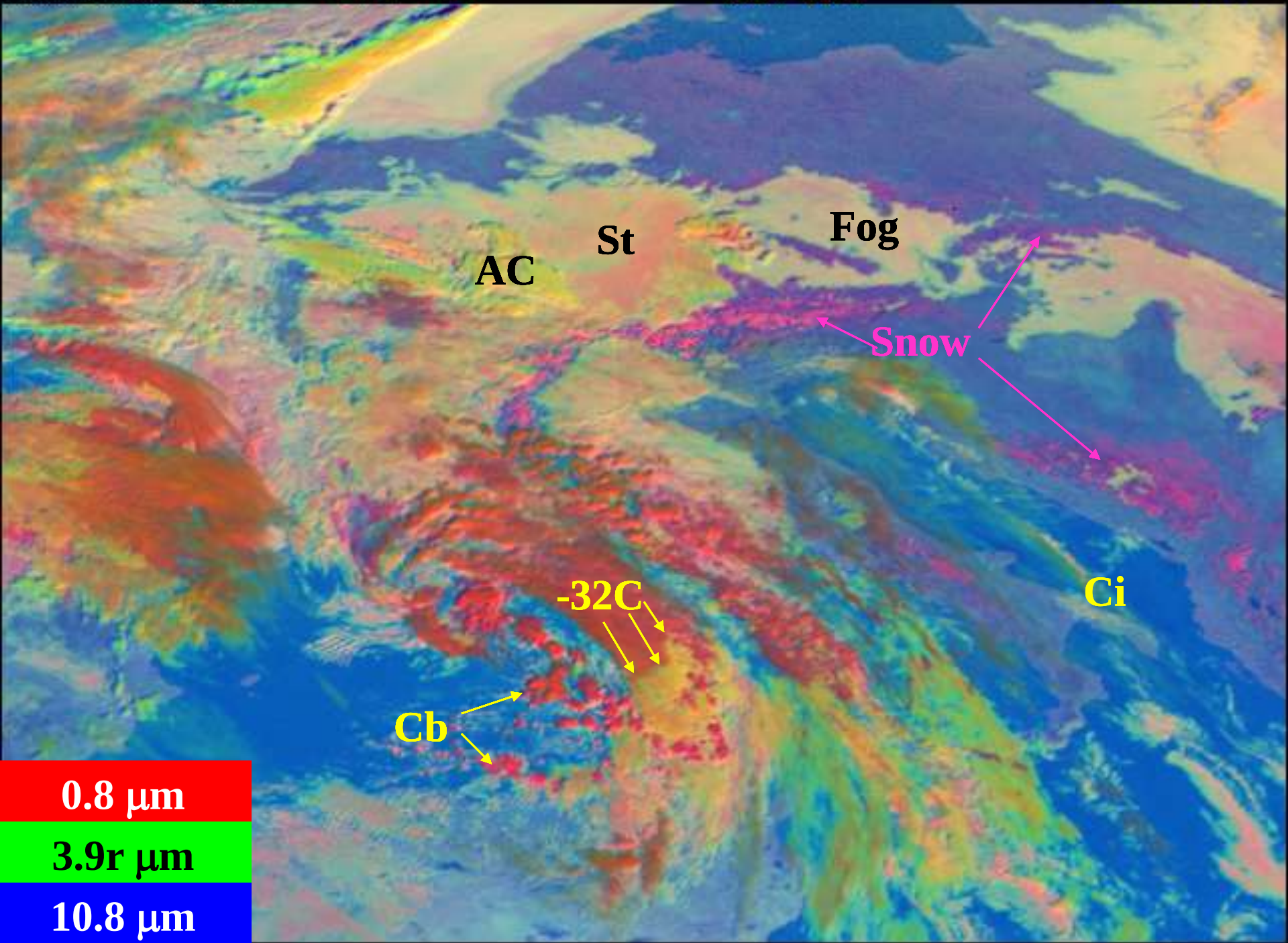
10.8i μm

2003/12/19 10:27

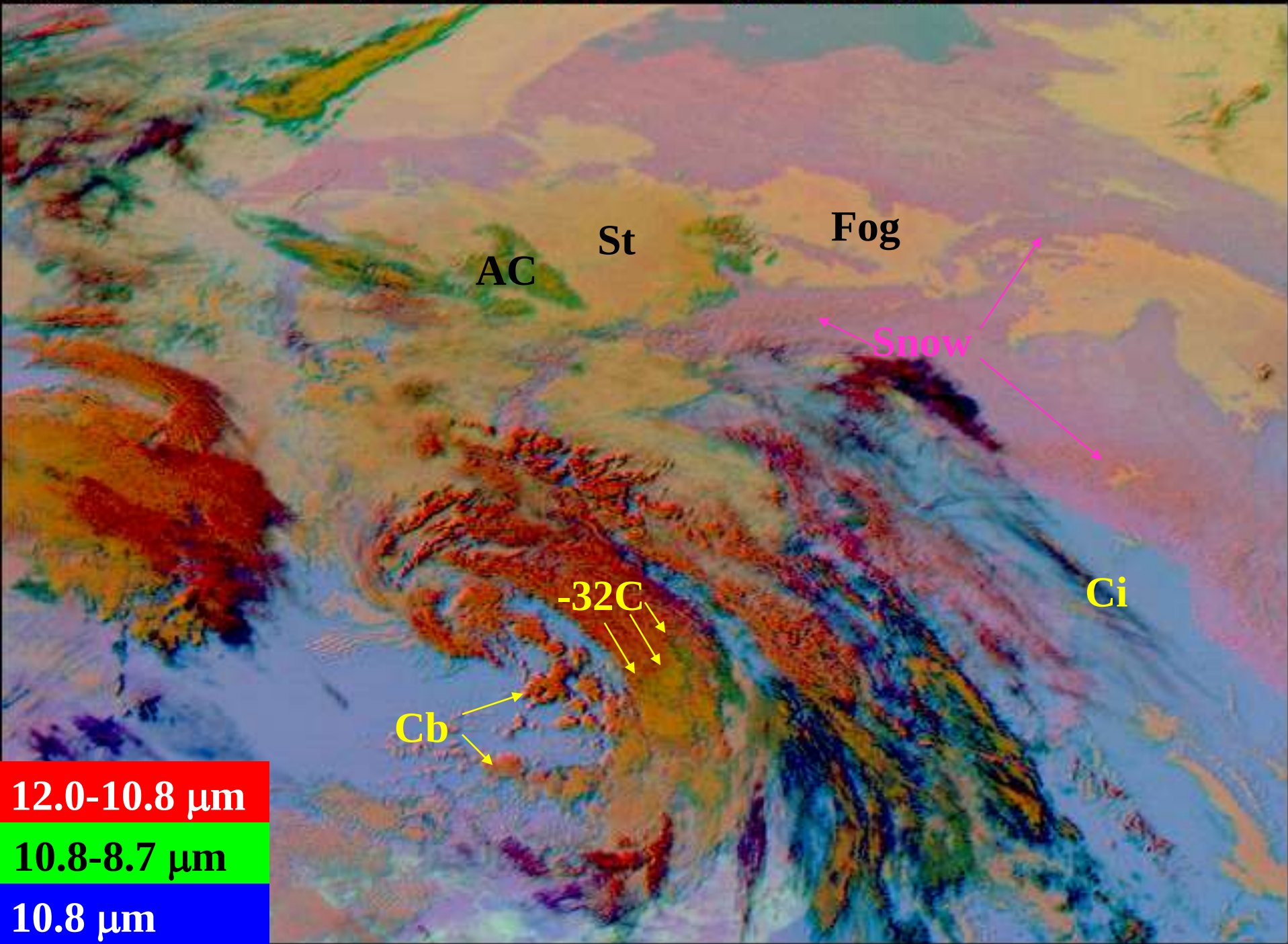
CH02 0.8

CH04 3.9

CH09 10.8



0.8 μm
3.9 μm
10.8 μm

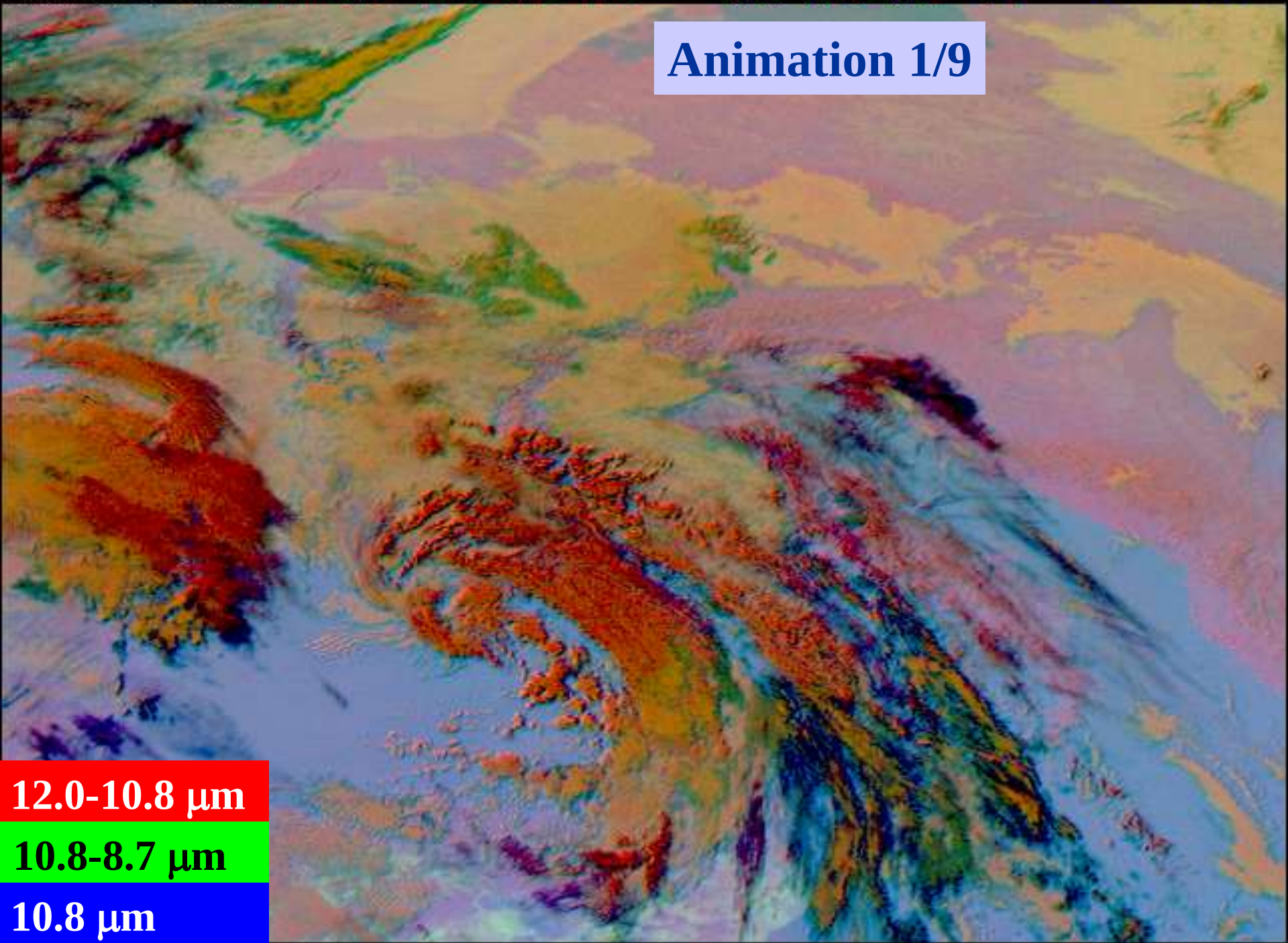


Animation 1/9

12.0-10.8 μm

10.8-8.7 μm

10.8 μm

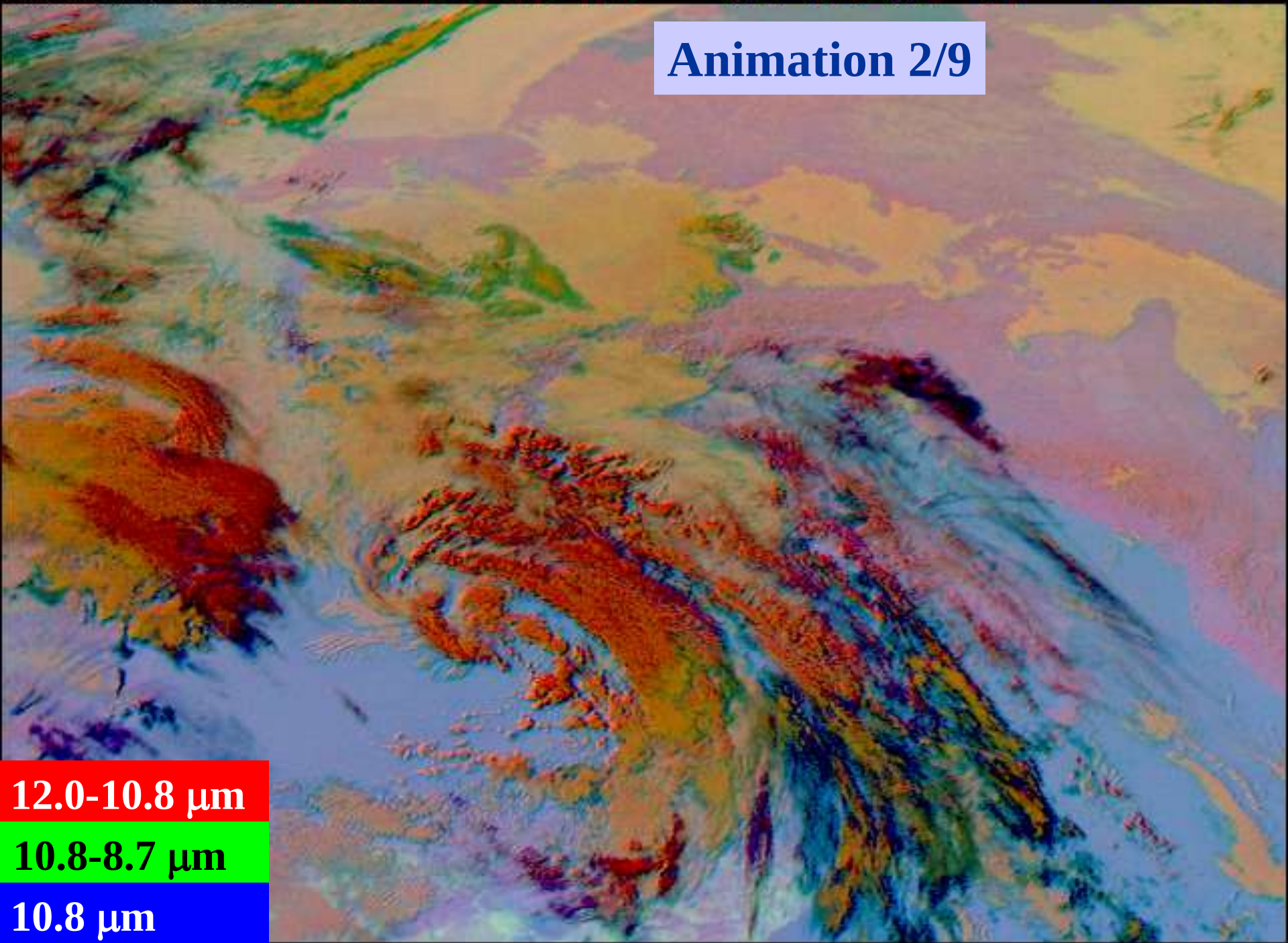


Animation 2/9

12.0-10.8 μm

10.8-8.7 μm

10.8 μm

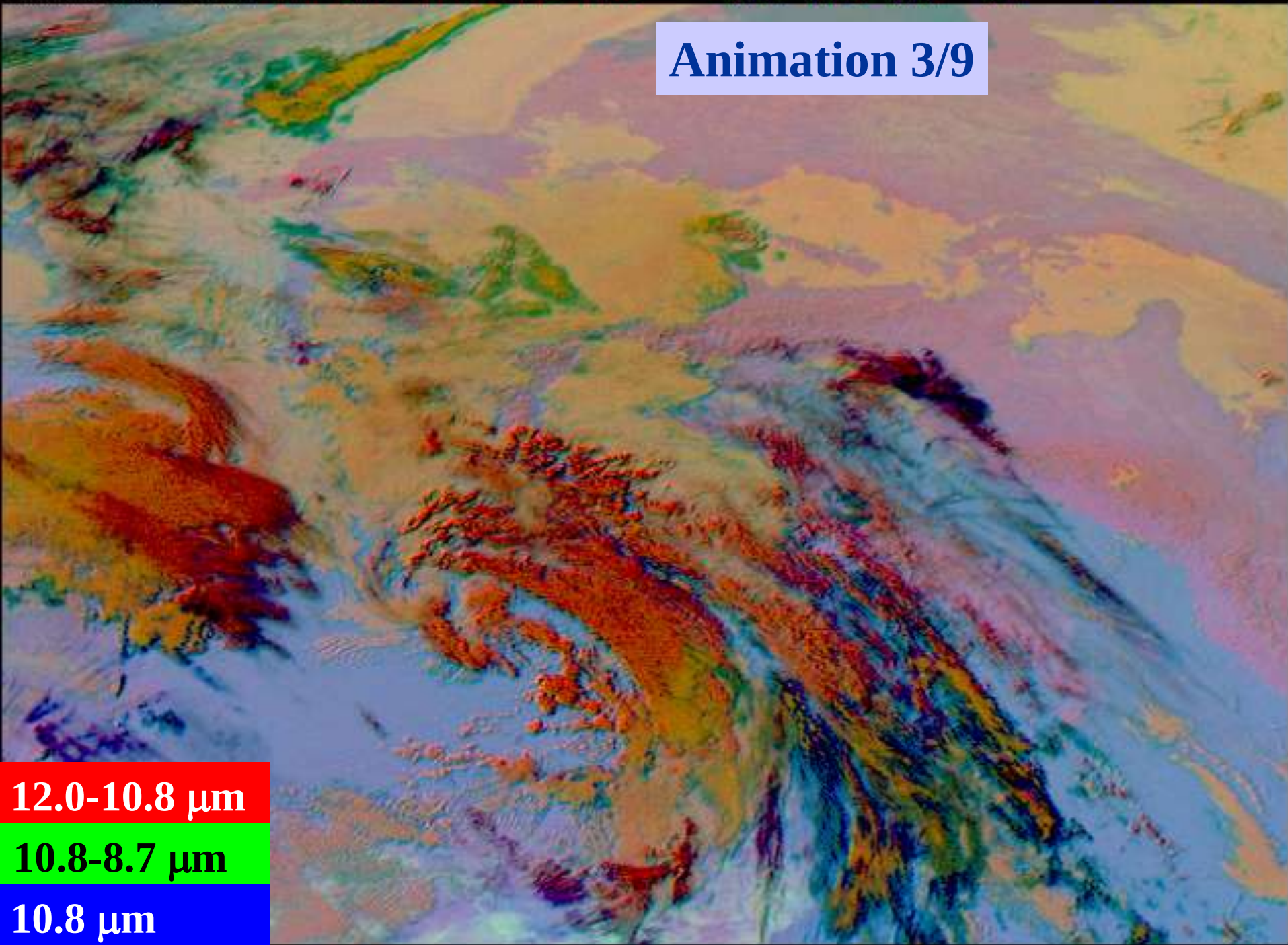


Animation 3/9

12.0-10.8 μm

10.8-8.7 μm

10.8 μm

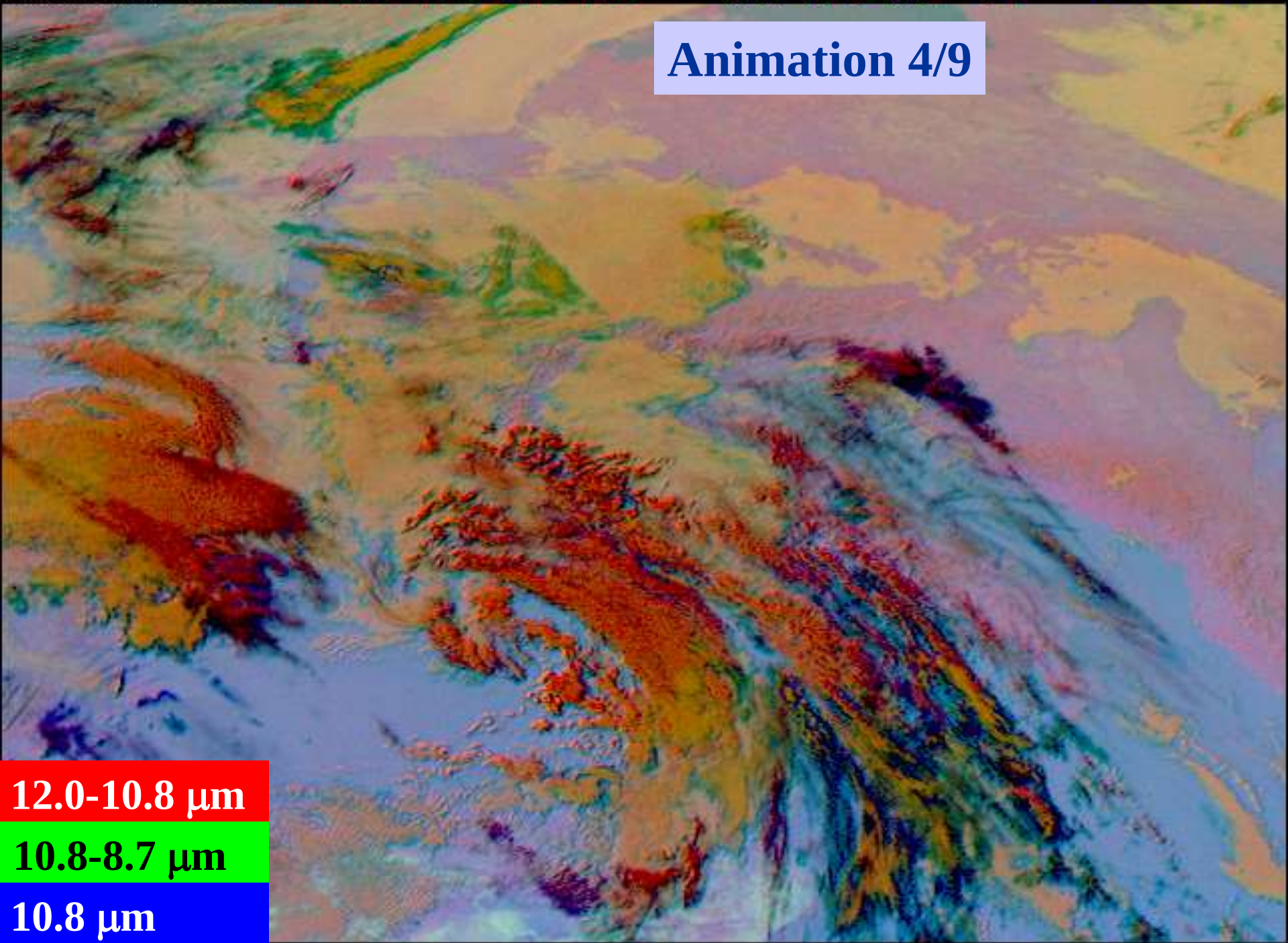


Animation 4/9

12.0-10.8 μm

10.8-8.7 μm

10.8 μm

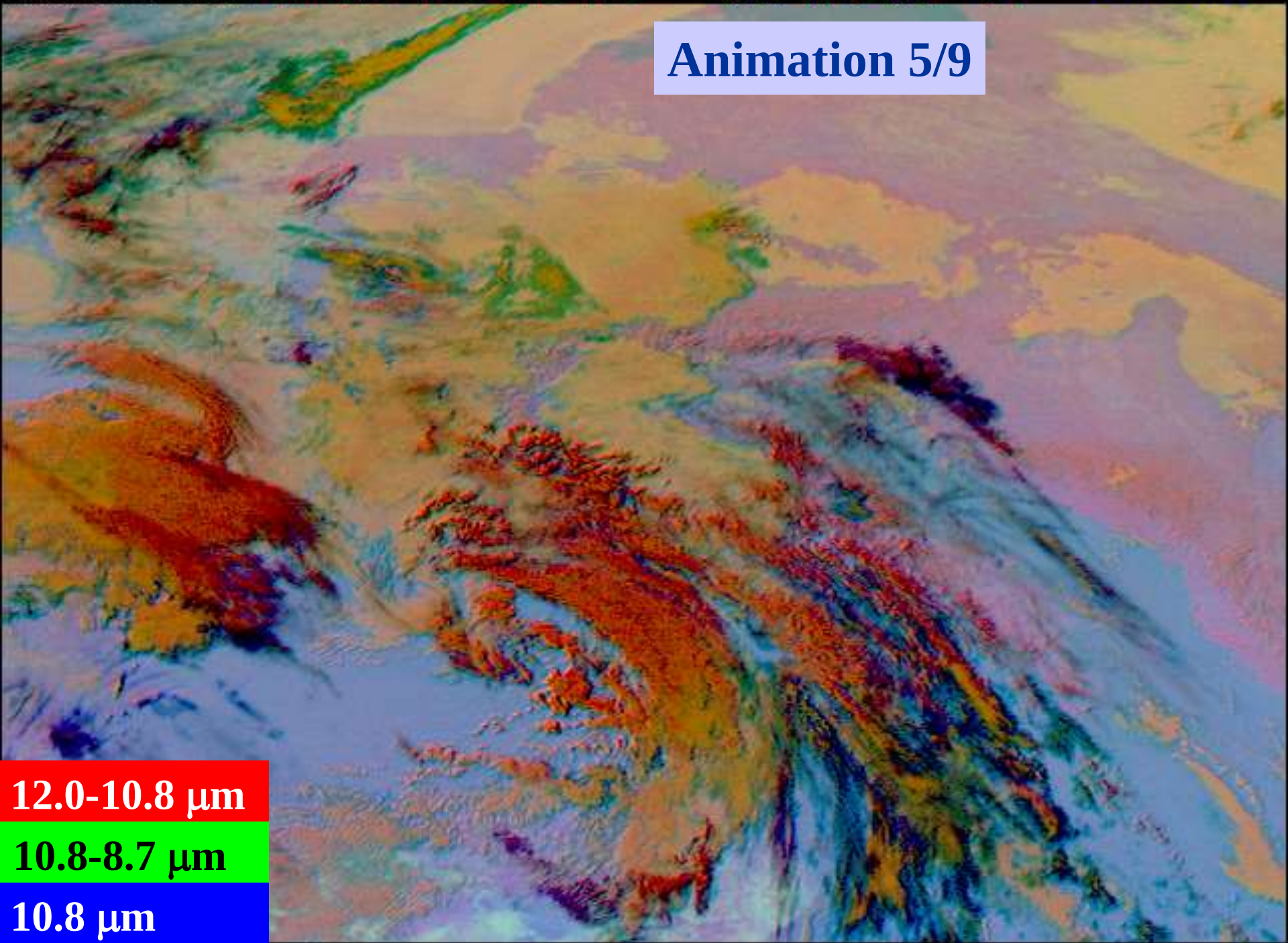


Animation 5/9

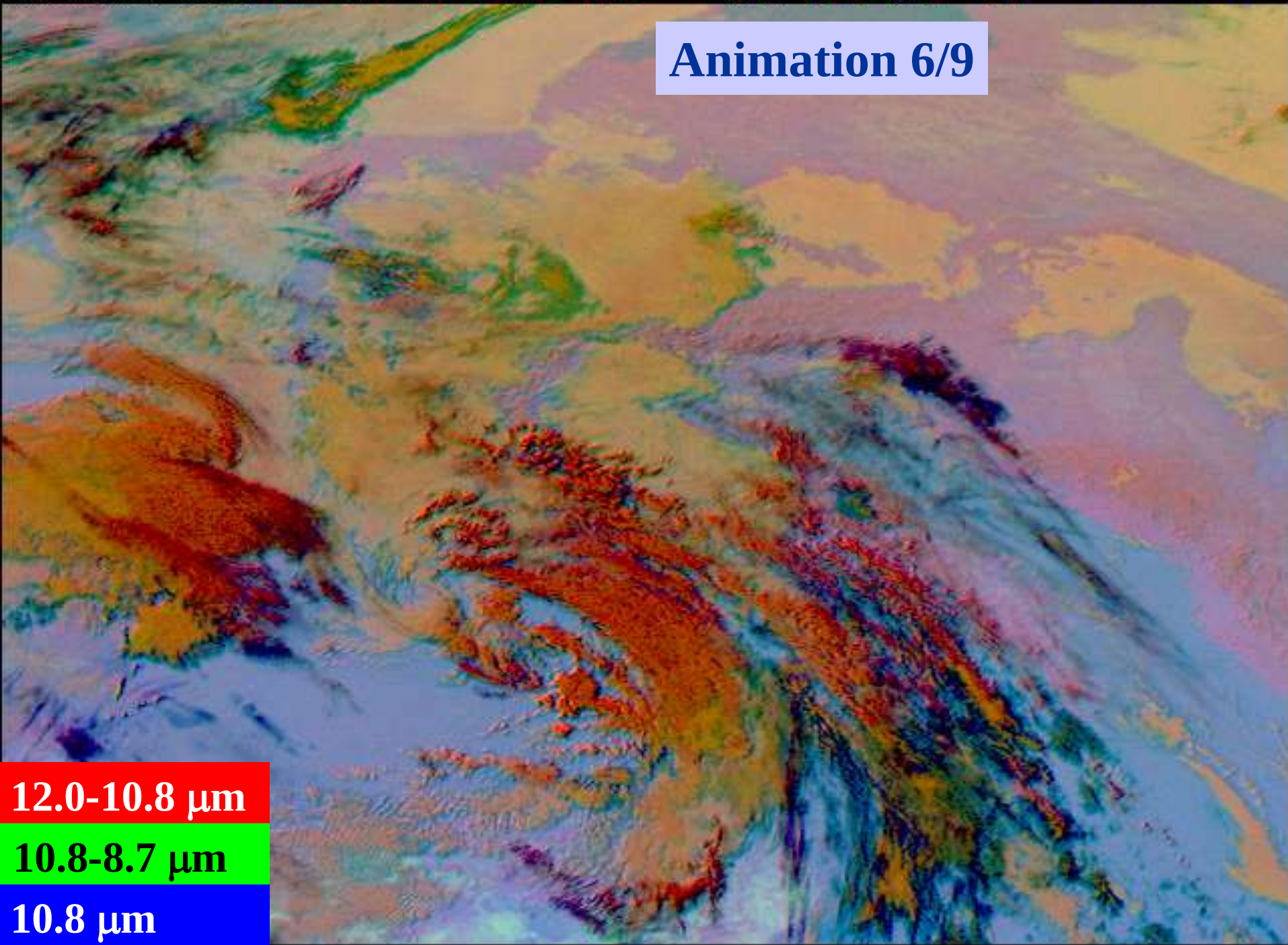
12.0-10.8 μm

10.8-8.7 μm

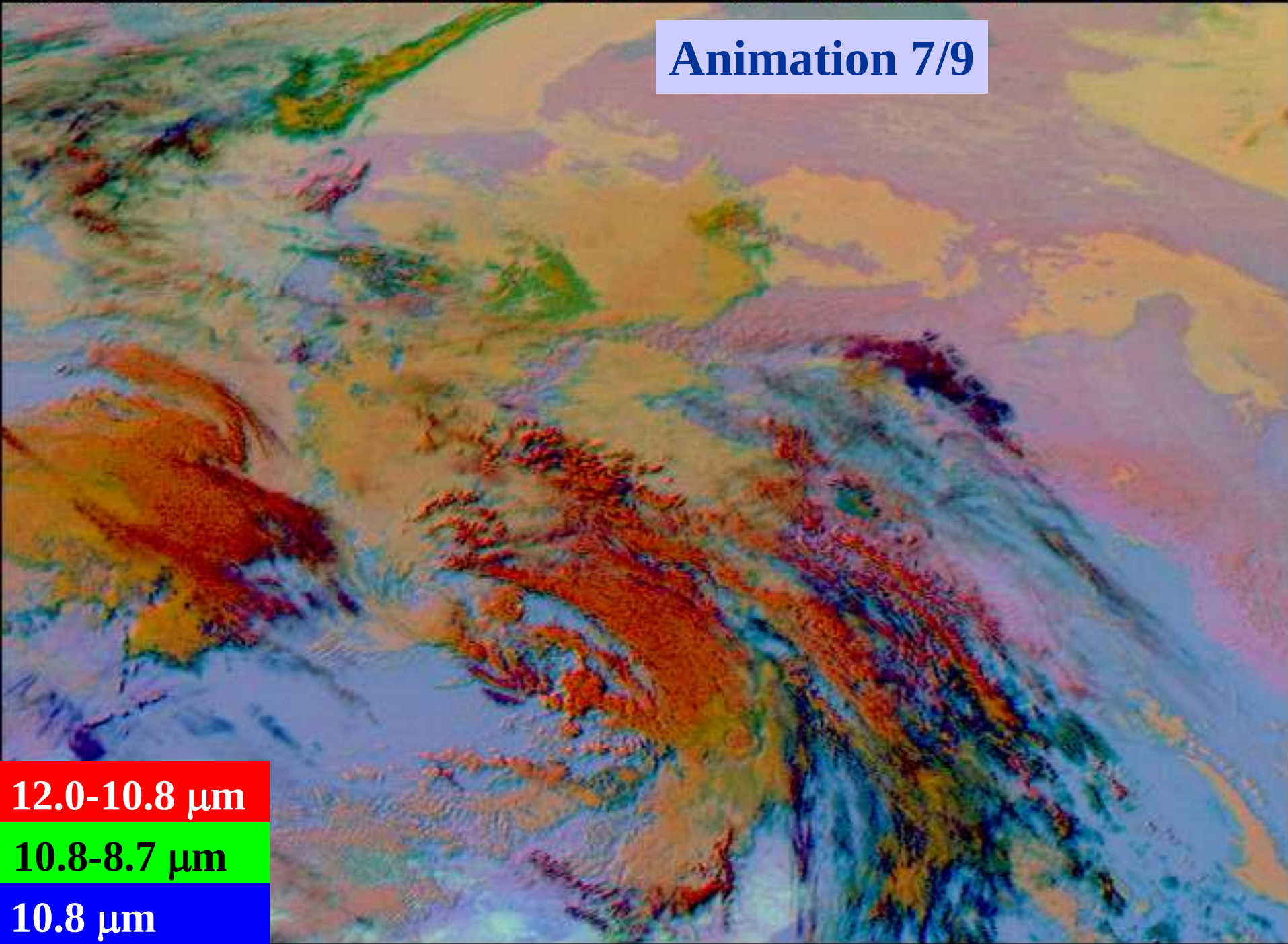
10.8 μm



Animation 6/9



Animation 7/9

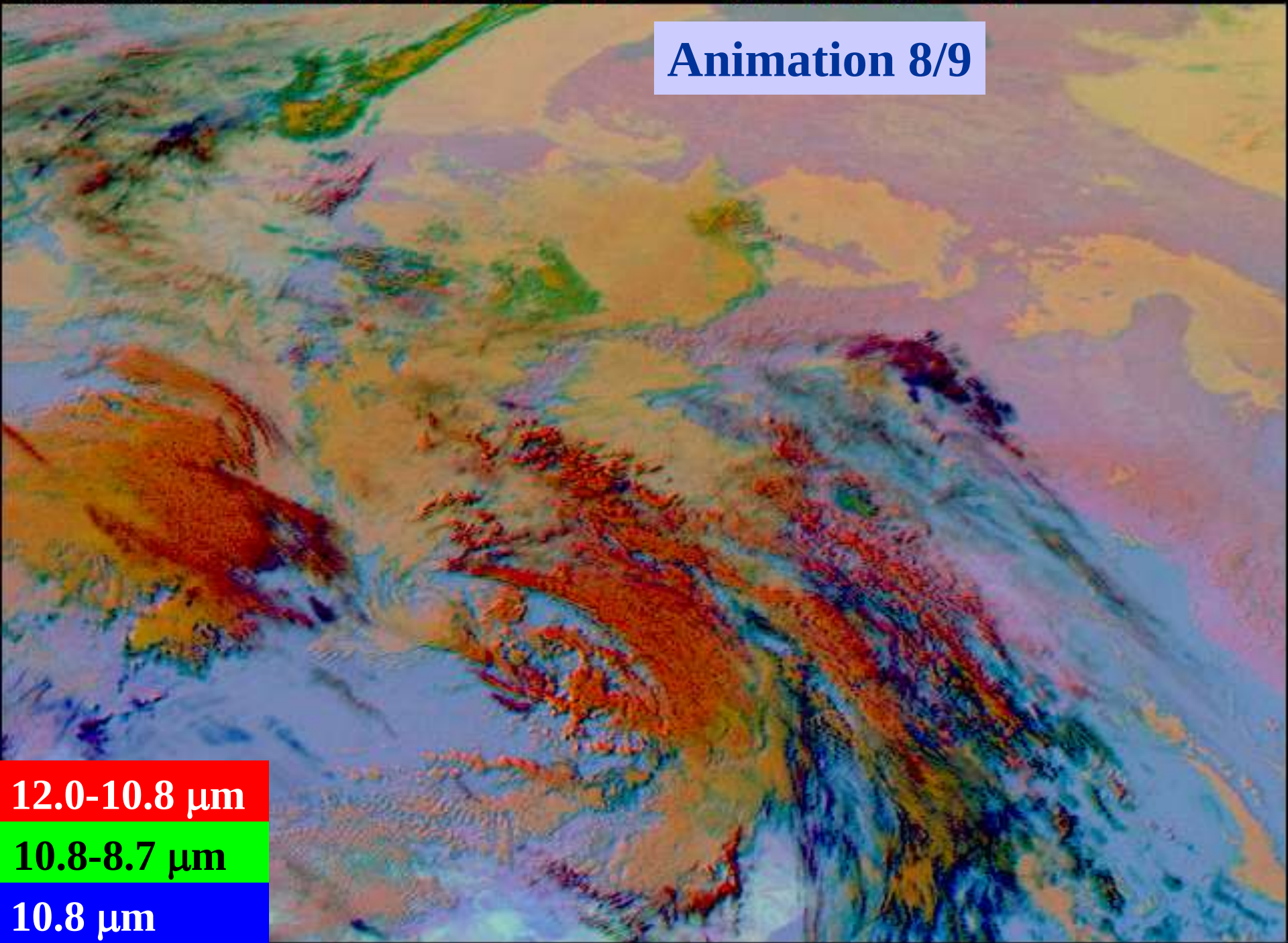


Animation 8/9

12.0-10.8 μm

10.8-8.7 μm

10.8 μm

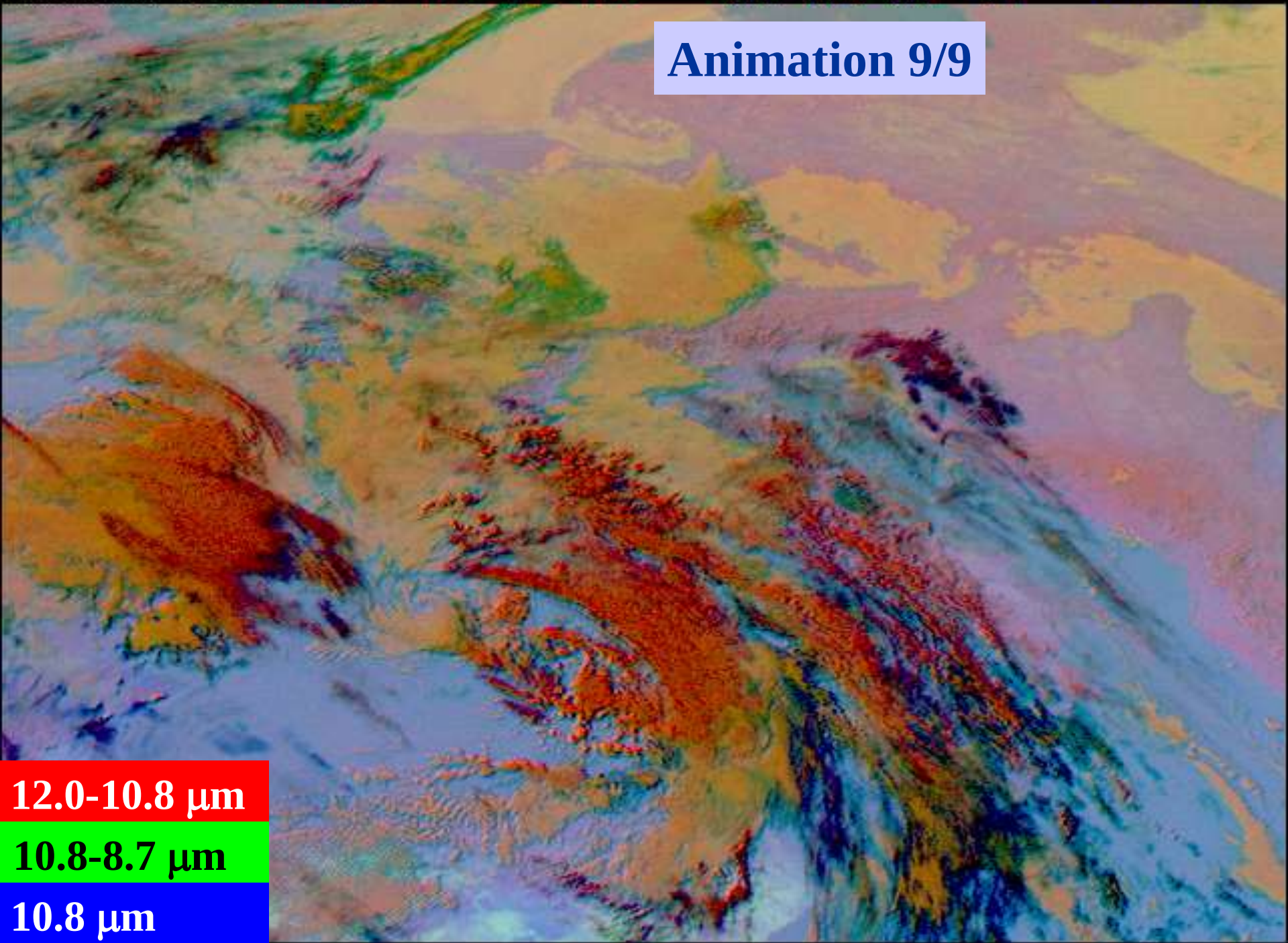


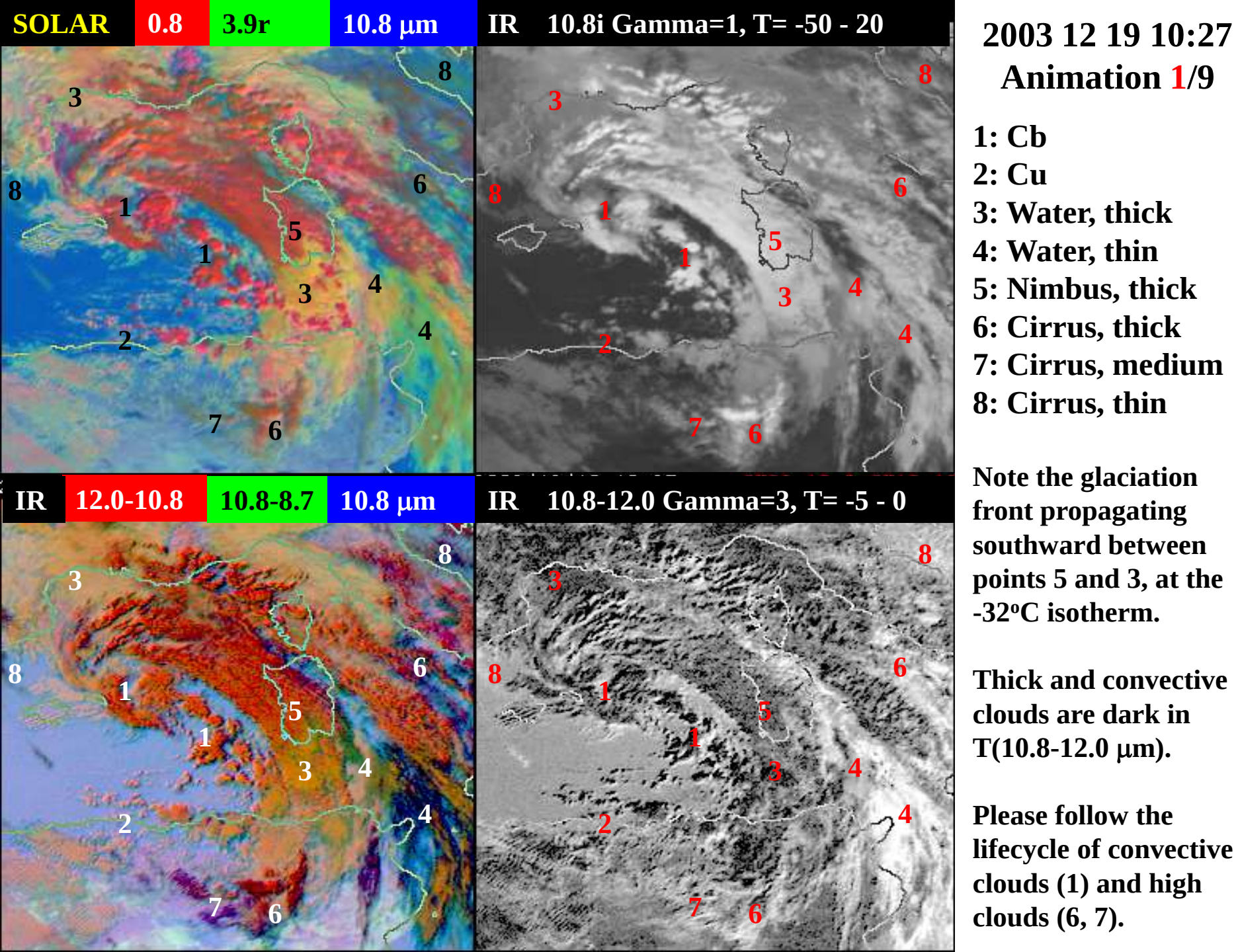
Animation 9/9

12.0-10.8 μm

10.8-8.7 μm

10.8 μm





Summary

The MSG has advanced our ability to identify cloud properties, composition, dynamics and precipitation, by using the MSG enhancements in spectral bands, spatial and time resolution.

This makes it possible for the duty forecaster to diagnose and nowcast a selection of phenomena, such as:

- **Fog**, by detecting warm layer clouds with small drops.
- **Drizzle**, by identifying thin clouds with large drops.
- **Rain clouds**, by thick clouds with tops of ice or large drops.
- **Intense convective storms**, by cold tops with small ice particles, and rate of expansion of the anvils.
- **Dissipating convective storms**, by warming and thinning of the glaciated tops.
- **Multi-layer clouds**, by renewed small particles in the base of each higher layer.
- Supercooled water clouds with **icing aviation hazard**, by small particles of clouds with top temperatures of $0^{\circ}\text{C} < T < -30^{\circ}\text{C}$.
- **Thin clouds**, by large brightness temperature differences.

Which RGB is this ?

- Dust RGB
- Airmass RGB
- Day Microphysics RGB
- Night Microphysics RGB

2005/09/07 13:12

CH02 0.8

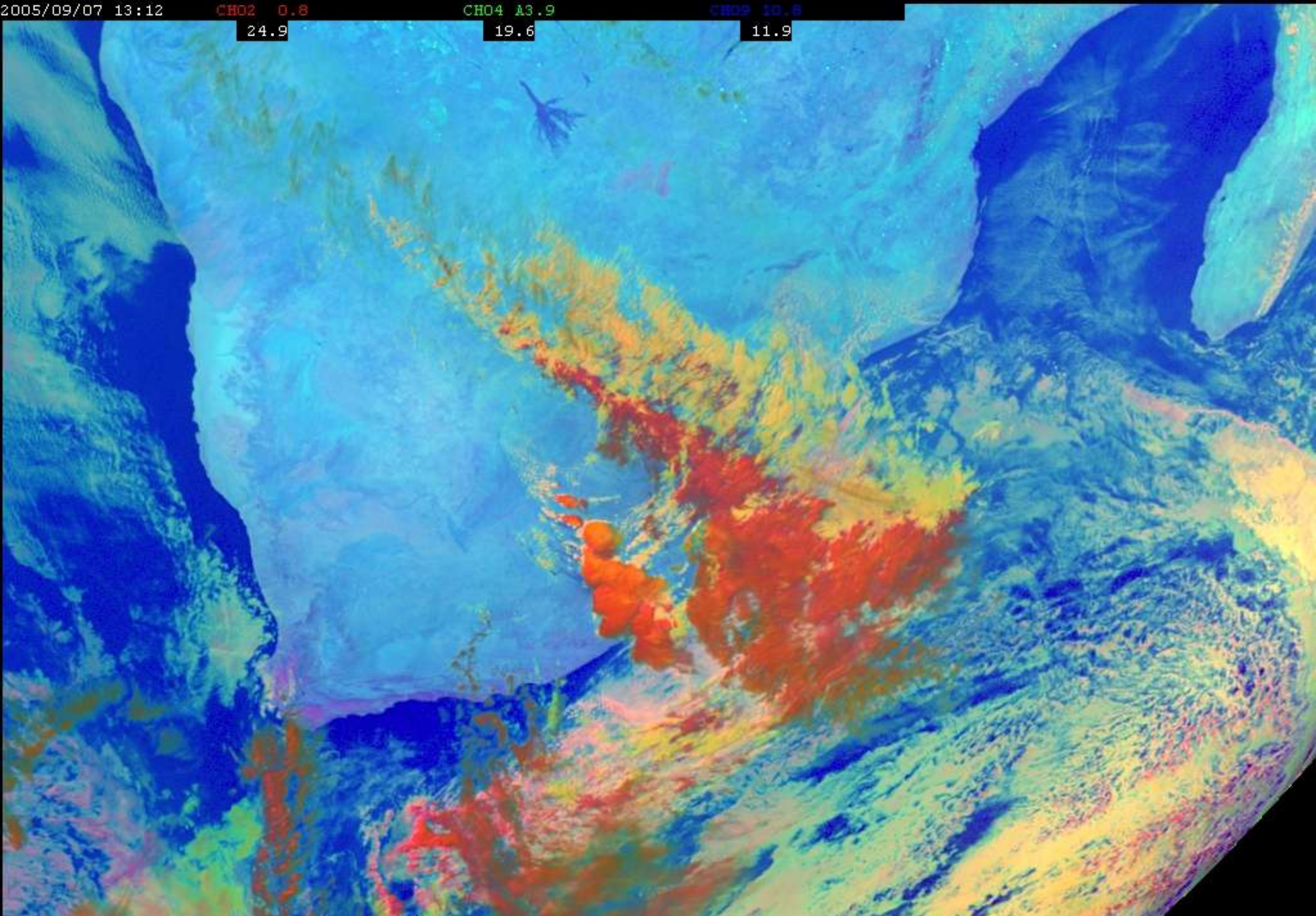
CH04 A3.9

CH08 10.8

24.9

19.6

11.9



7 Sep 2005, 13:00 UTC, RGB Day Microphysics

Precipitation Monitoring

Which of the following clouds are producing ground-level precipitation ?



26 Aug 2005, 12:00 UTC, RGB Day Microphysics

Precipitation Monitoring

Which of the following clouds are producing on-ground precipitation ?

Solution:

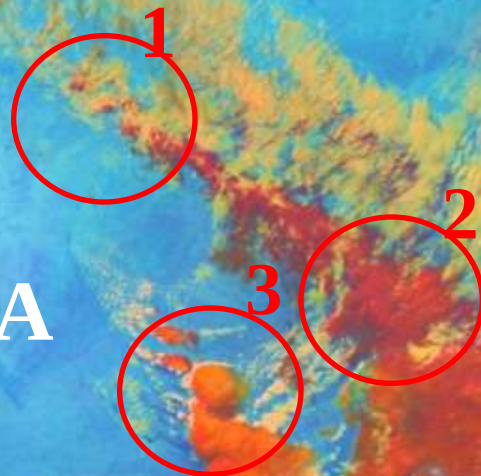
Area 1 (warm rain process)
&
Area 3 (cold rain process)



Nowcasting Convection

Which of the following
convective storms
look more severe ?

RSA



7 Sep 2005, 13:00 UTC, RGB Day Microphysics

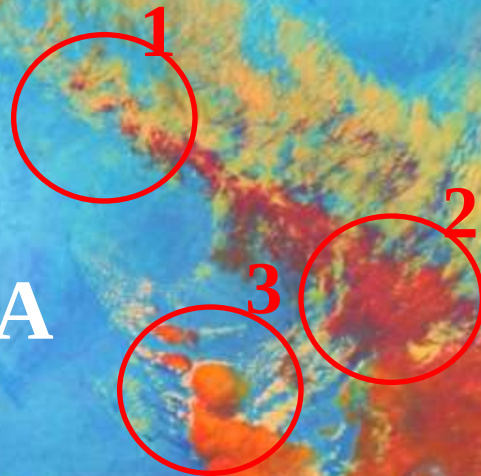
Nowcasting Convection

Which of the following
convective storms
look more severe ?

Solution:

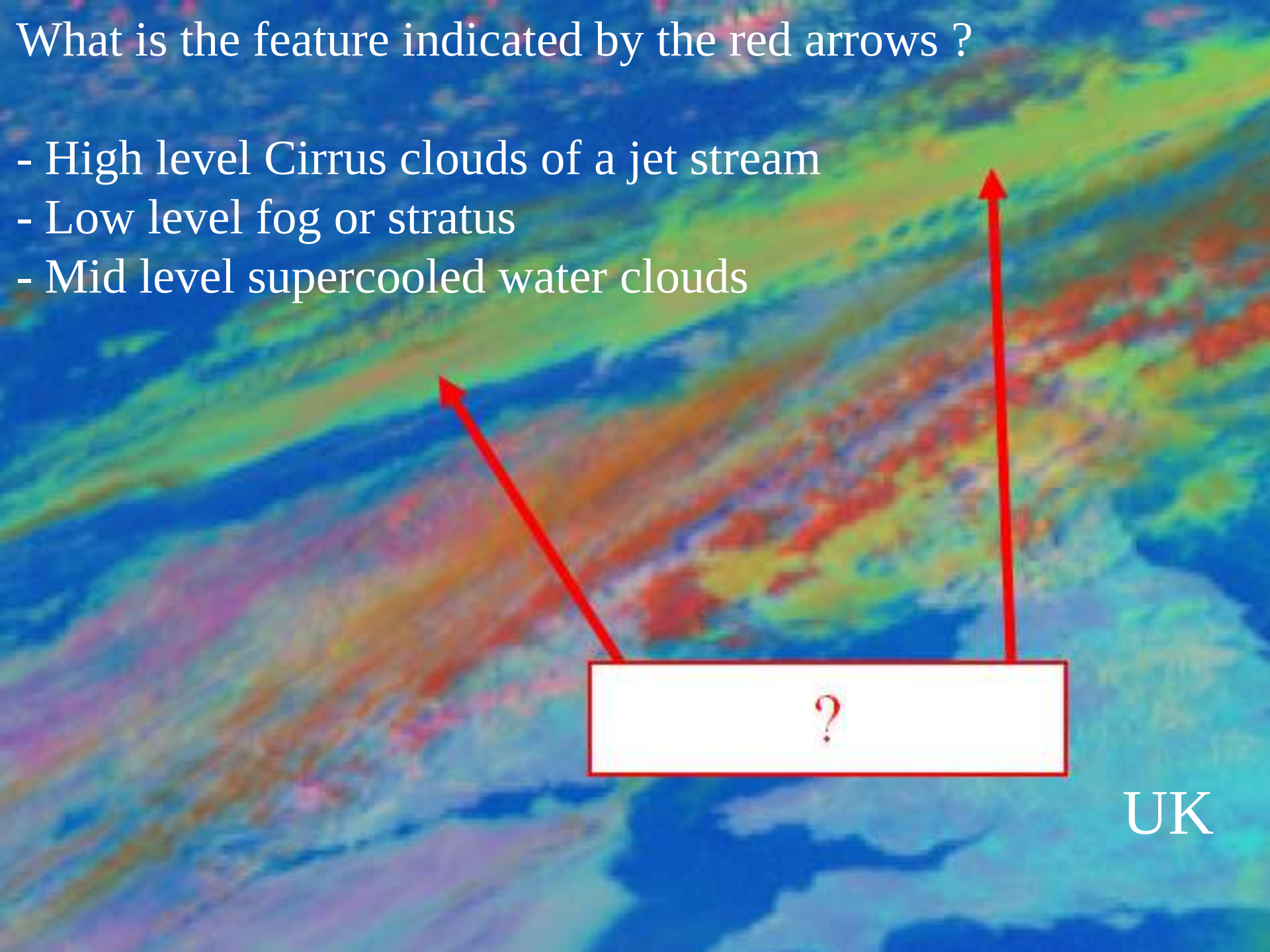
Area 3
(strong winds, hail
& tornado observed)

RSA



What is the feature indicated by the red arrows ?

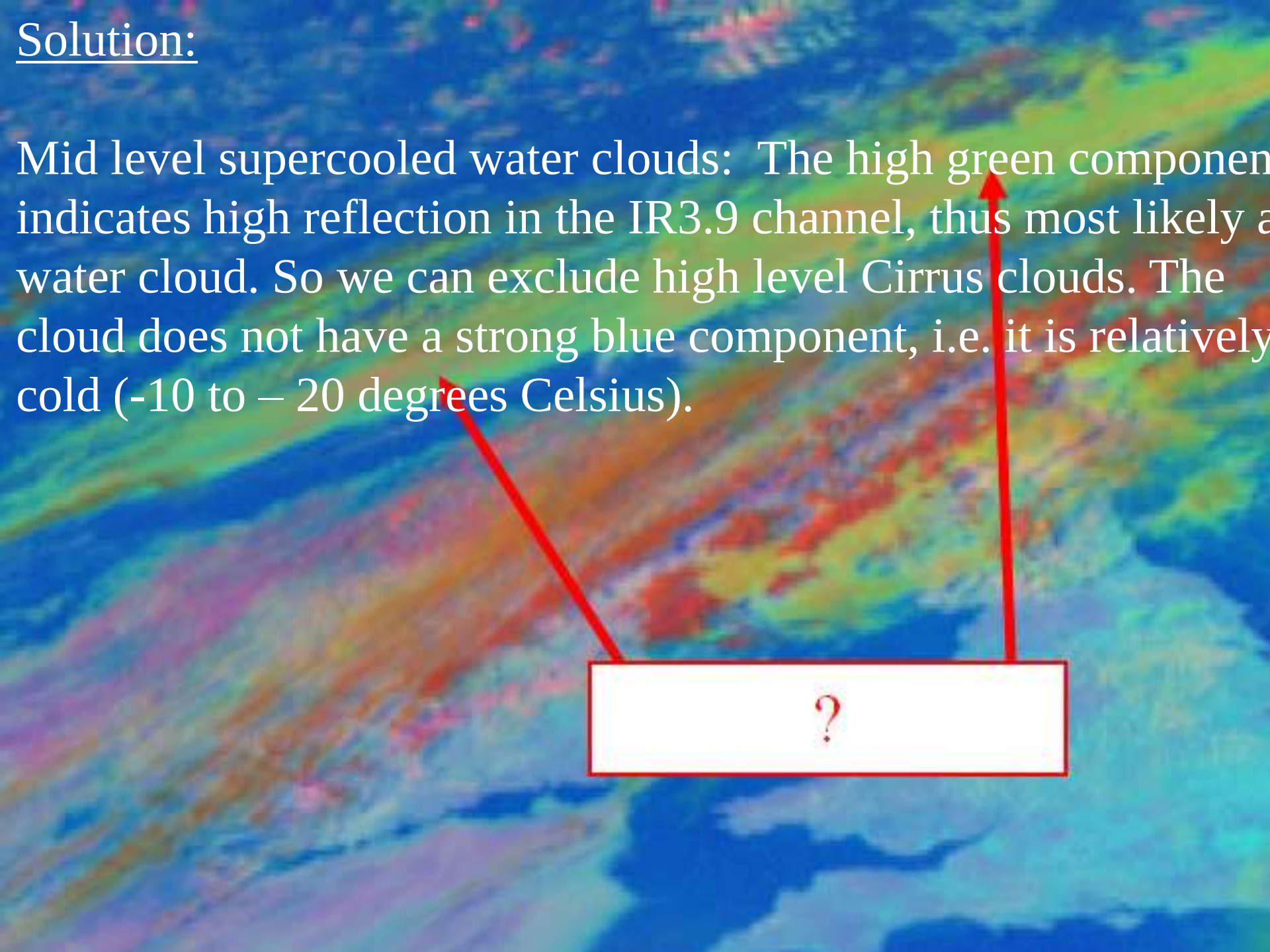
- High level Cirrus clouds of a jet stream
- Low level fog or stratus
- Mid level supercooled water clouds



UK

Solution:

Mid level supercooled water clouds: The high green component indicates high reflection in the IR3.9 channel, thus most likely a water cloud. So we can exclude high level Cirrus clouds. The cloud does not have a strong blue component, i.e. it is relatively cold (-10 to -20 degrees Celsius).



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