- Geostationary satellites (altitude, 36000 km)

- Polar-orbiting satellites (altitude 8-900 km, period order 100 min)

- Time does not permit to cover the contribution of satellites – including Canadian satellites – to studies pertaining to global change and global climatology, e.g. measuring the solar constant, atmospheric CO2 and other trace gases, aerosols

- Nor the many other useful means of actively remotely sensing the atmosphere using electromagnetic or acoustic waves, e.g. doppler acoustic “sodar” gives wind velocities in lowest kilometer

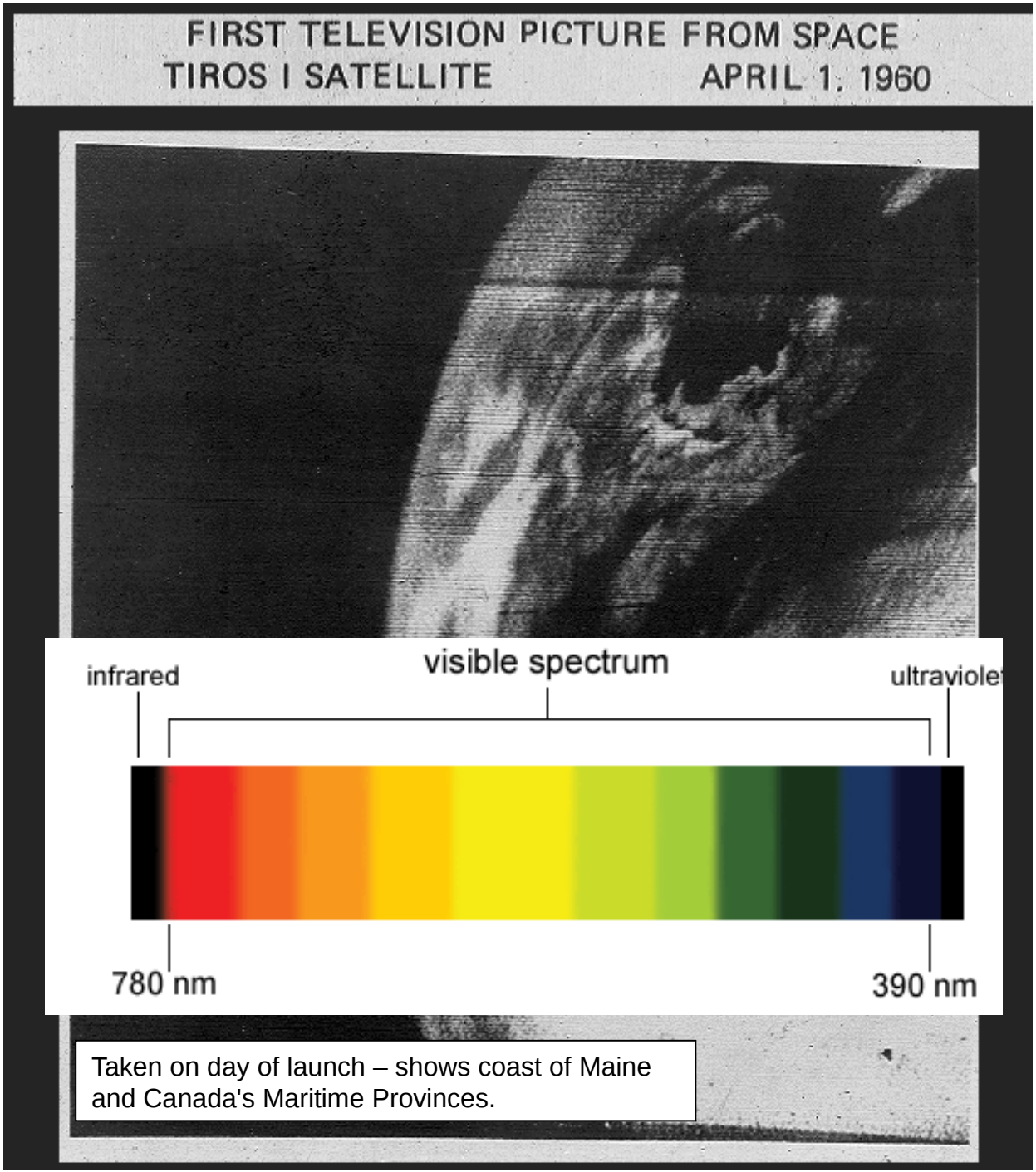
Visible satellite imagery

- daytime only; whiteness of each pixel proportional to the amount of visible radiation received by the satellite from the solid angle subtended by the pixel at the detector

- relative positions of the sub-solar point and the sub-satellite point, even in the daytime configuration, exert an influence on the image (eg. if satellite and sun were both directly overhead from point P, the image at point P would display no shadows)

- distinctions in albedo (shortwave reflectivity) allow to distinguish features

TIROS



- first “Television InfraRed Observation Satellite”
- near circular orbit (~ 800 km) inclined 48 degrees to the equatorial plane
- operational 78 days (1,302 orbits)
- 0.6 m by 1.1 m diam, 122 kg
- launch of NOAA-19 6Feb.09, last of “Advanced TIROS-N” series of Polar Operational Environmental Satellites (POES)
- new generation U.S. polar-orbiting, non-geosynchronous, environmental satellites the "Joint Polar Satellite System." JPSS 1 will launch Nov. 2016

Orbit of geostationary satellite

An equilibrium orbit at height *h* above earth's surface results, when earth's gravitational pull on the satellite balances the centripetal acceleration, i.e.

$$G\frac{m\ M_e}{(R_e+h)^2} = \frac{m\ V^2}{R_e+h} \longrightarrow G\frac{M_e}{(R_e+h)} = V^2$$

where

- satellite's mass *m*
- Newton's gravitational constant *G* = 6.673 x 10^{-11} [N m^2 kg^{-2}]
- earth's mass M_e = 5.98 x 10^{24} kg
- earth's radius R_e = 6.368 x 10^6 m
- *V* is the linear velocity of the satellite
- angular velocity of the satellite

eliminate *V* to get an eqn. with one unknown (*h*)

$$\Omega = \frac{V}{R_e+h} = \frac{2\pi}{24\times 3600} \longrightarrow V = 2\pi\frac{R_e+h}{24\times 3600}$$

Exercise: compute the orbital period of NOAA-18, with altitude h = 870 km

$$G \frac{M_e}{(R_e + h)} = V^2$$

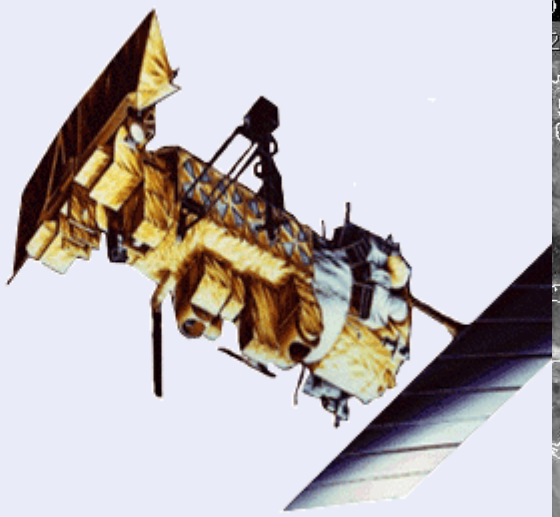
- G = 6.673 x 10^{-11} [N m^2 kg^{-2}]
- M_e = 5.98 x 10^{24} kg
- R_e = 6.368 x 10^6 m

NOAA-N is a polar-orbiting satellite developed by NASA for the National Oceanic and Atmospheric Administration... the 15th in a series of polar-orbiting satellites dating back to 1978. NOAA uses two satellites, a morning and afternoon satellite, to ensure every part of the Earth is observed at least twice every 12 hours. NOAA-N launched from Vandenberg Air Force Base, Calif. at 6:22:01.566 a.m. EDT on Friday, May 20, 2005

POES NOAA-19 viz. 1.6 µm (nir) 1757Z Wed. 18 March 2015

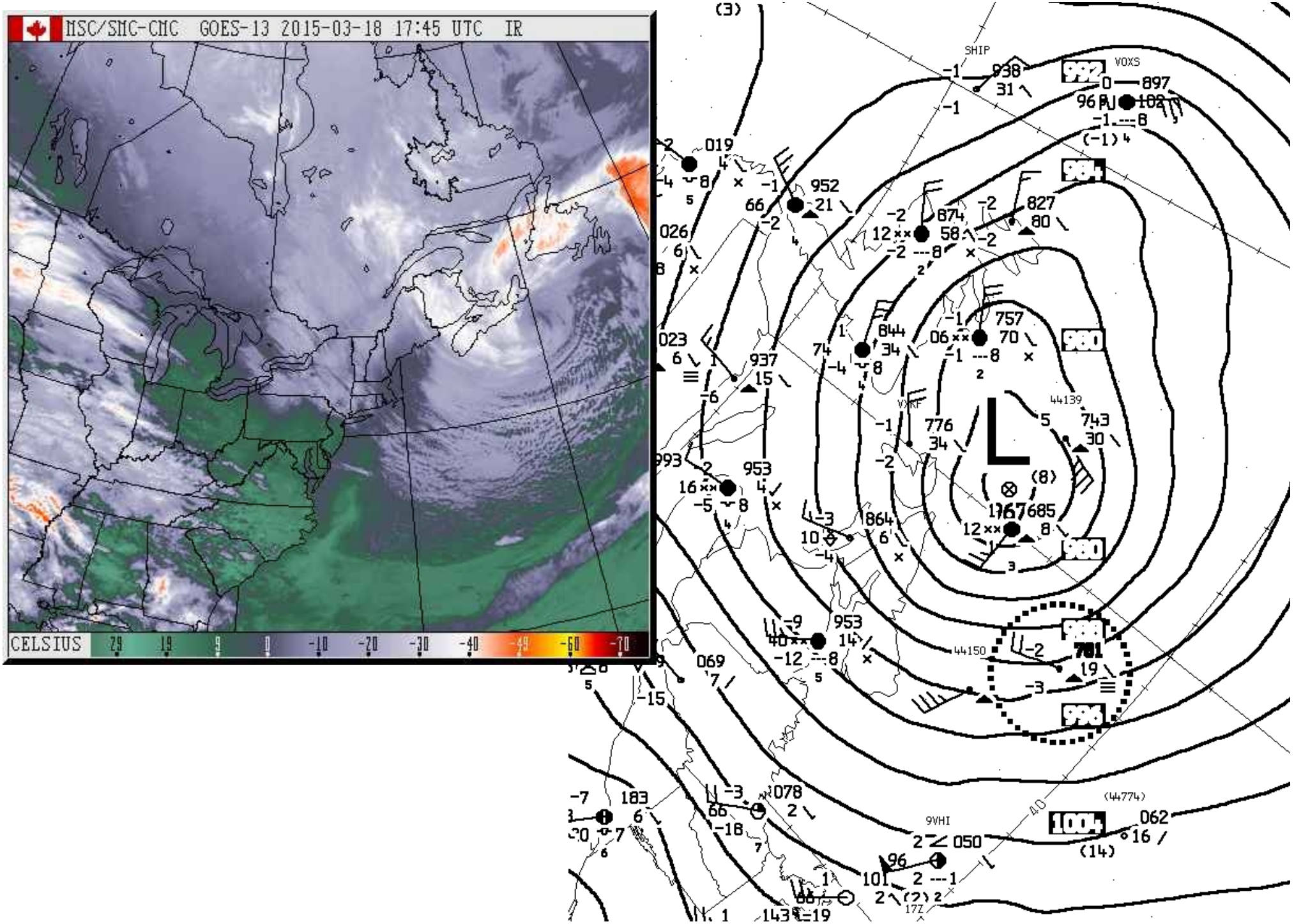
Active Spacecraft and Mission Status

Spacecraft	Mission Operational Status
METOP-B	AM Primary
METOP-A	AM Backup
NOAA 11	Decomissioned 16 June 2004.
NOAA 12	Decommissions 10 Aug 2007
NOAA 14	Decommission on 23 May 07
NOAA 15	AM Secondary
NOAA 16	PM Secondary
NOAA 17	Decommission on 10 April, 2013
NOAA 18	PM Secondary
NOAA 19	PM Primary



Two polar orbiting satellites known as the Advanced Television Infrared Observation Satellites (TIROS) - N (ATN). Operating as a pair, these satellites ensure infrared and non-visible data for any region of the Earth are no more than six hours old.

CMC 18Z analysis Wed. 18 March 2015 (& GOES east ir 10.7 µm at 1745)



NOAA's GOES and POES satellites

NOAA OFFICE OF SATELLITE AND PRODUCT OPERATIONS
NATIONAL ENVIRONMENTAL SATELLITE, DATA, AND INFO

ORGANIZATION | SERVICES | PRODUCTS | OPERATIONS

GOES 15 Operational Status

The Geostationary Operational Environmental Satellites (GOES) spacecraft status page provides up to date status information on GOES-15 and its various subsystems.

GOES 15 Spacecraft Status Summary

Spacecraft Letter: P
Launch Date: 03/04/2010
Spacecraft Location: 135.0 West
Notes: GOES-15 arrived 135.0W on 12/14/2011.

Operational Date: 12/06/2011
AOCS Mode: Normal Upright
Operational Status: Operation West

Subsystem Status:

Subsystem	Description	Status
ACS	Attitude Control System	YELLOW
COMM	Communication Subsystem	YELLOW
IMAGER	Imager	GREEN
INR	Image Navigation and Registration	GREEN
POWER	Electrical Power Subsystem	GREEN
PROP	Propulsion	GREEN
SEM	Space Environment Monitor	GREEN
SOUNDER	Sounder	YELLOW
SXI	Solar X-Ray Imager	GREEN
TANDC	Telemetry & Command	GREEN
THERMAL	Thermal Control Subsystem	GREEN

GOES P is GOES-15, present GOES-west

Active Spacecraft and Operational Status

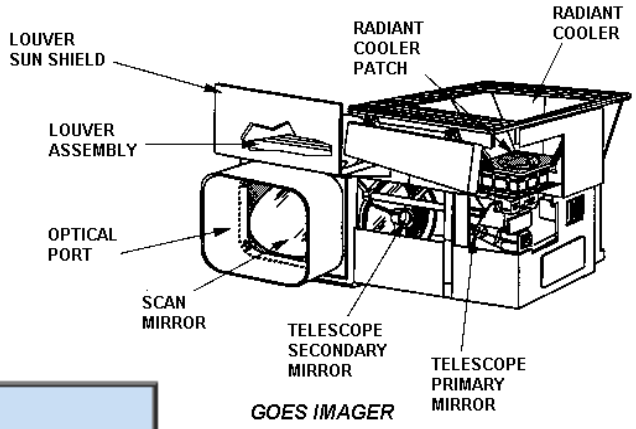
Spacecraft	Operational Status	Status
GOES 8	Decommissioned	RED
GOES 9	Decommissioned	RED
GOES 10	Decommissioned	RED
GOES 11	Decommissioned	RED
GOES 12	Decommissioned	RED
GOES 13	Operational East	GREEN
GOES 14	On-Orbit Storage	GREEN
GOES 15	Operational West	GREEN

Status Color		Meaning
GREEN	=	Operational (or capable of)
YELLOW	=	Operational with limitations (or Standby)
ORANGE	=	Operational with Degraded Performance
RED	=	Not Operational

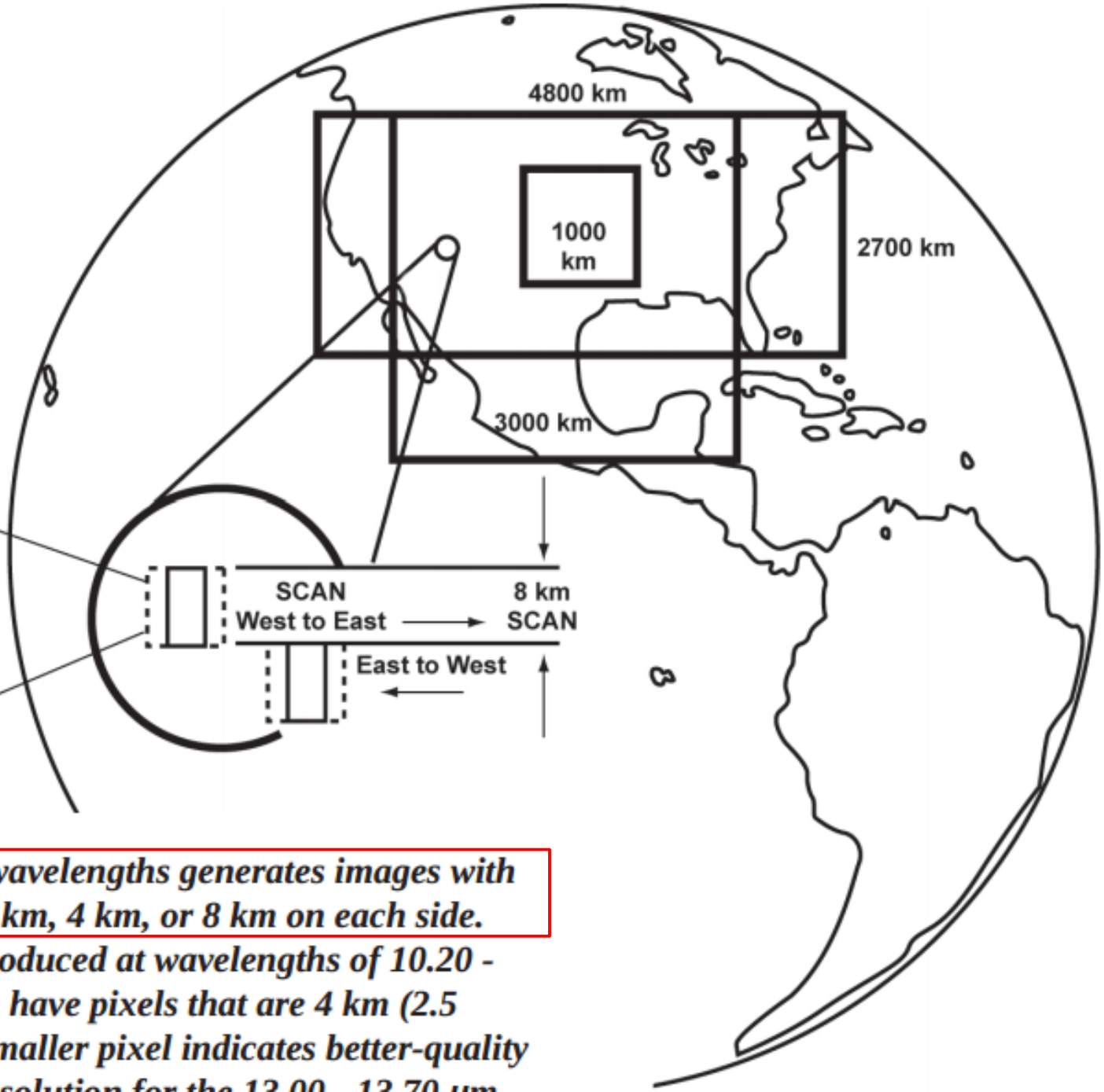
NOAA's GOES carry **imager** and **sounder**

- techniques are "passive"

"GOES West" is GOES 15 which is "P"



Imager Instrument Characteristics (GOES I-M)					
Channel number:	1 (Visible)	2 (Shortwave)	3 (Moisture)	4 (IR 1)	5 (IR 2)
Wavelength range (um)	0.55 - 0.75	3.80 - 4.00	6.50 - 7.00	10.20 - 11.20	11.50 - 12.50
Instantaneous Geographic Field of View (IGFOV) at nadir	1 km	("near ir") 4 km	8 km	4 km	4 km
Radiometric calibration	Space and 290 K infrared internal backbody				
Calibration frequency	Space: 2.2 sec (full disc), 9.2 or 36.6 sec (sector/area) Infrared: 30 minutes typical				
System absolute accuracy	IR channels: less than or equal to 1 K Visible channel: 5% of maximum scene irradiance				
Imaging rate	Full earth disc, less than or equal to 26 minutes				



IMAGER SCANNING	
GOES N	GOES O&P
13.35 µm (one 8 km) 3.9, 6.55, and 10.7 µm (two 4 km) Visible (eight 1 km)	3.9, 6.55, 10.7, and 13.35 µm (two 4 km) Visible (eight 1 km)

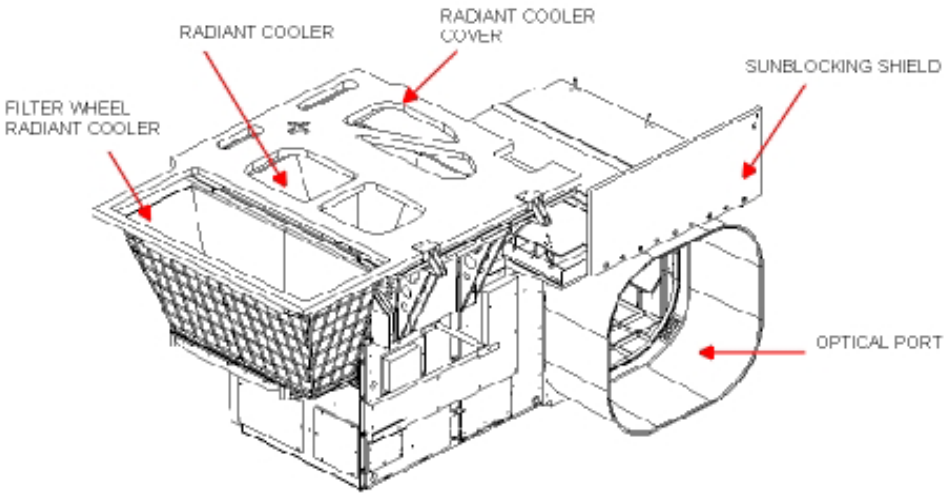
Each range of Imager wavelengths generates images with square pixels that are 1 km, 4 km, or 8 km on each side.

For instance, images produced at wavelengths of 10.20 - 11.20 micrometers (µm) have pixels that are 4 km (2.5 miles) on each side. A smaller pixel indicates better-quality images. Note that the resolution for the 13.00 - 13.70 µm wavelength changes for GOES-O&P, from 8km to 4 km.

GOES Area Scan

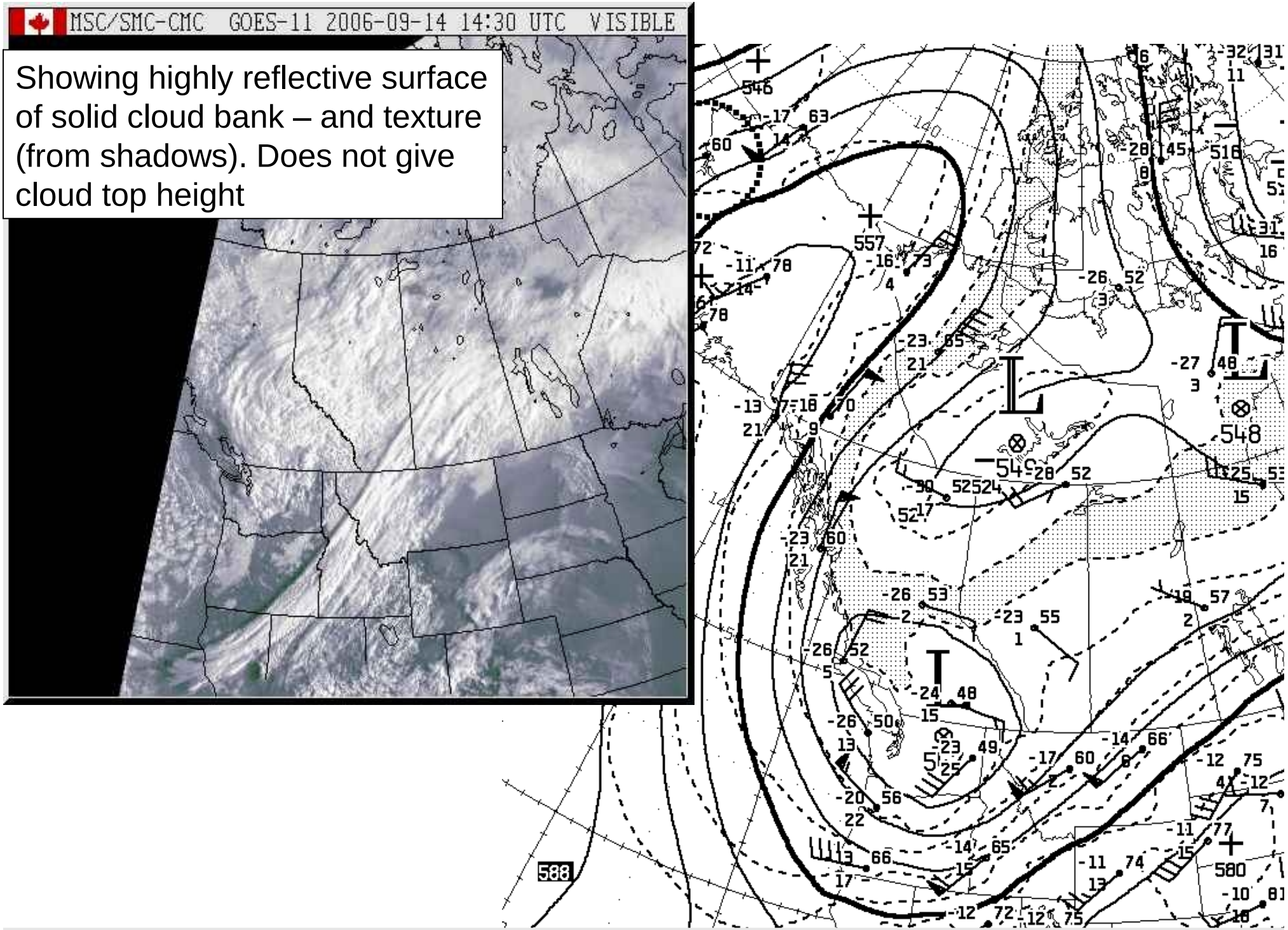
"The GOES **Sounder** is a 19-channel radiometer covering the spectral range from the visible to 15 microns… designed to provide data from which atmospheric temperature and moisture profiles, surface and cloud-top temperatures, and ozone distribution can be deduced"

GOES N-P Sounder

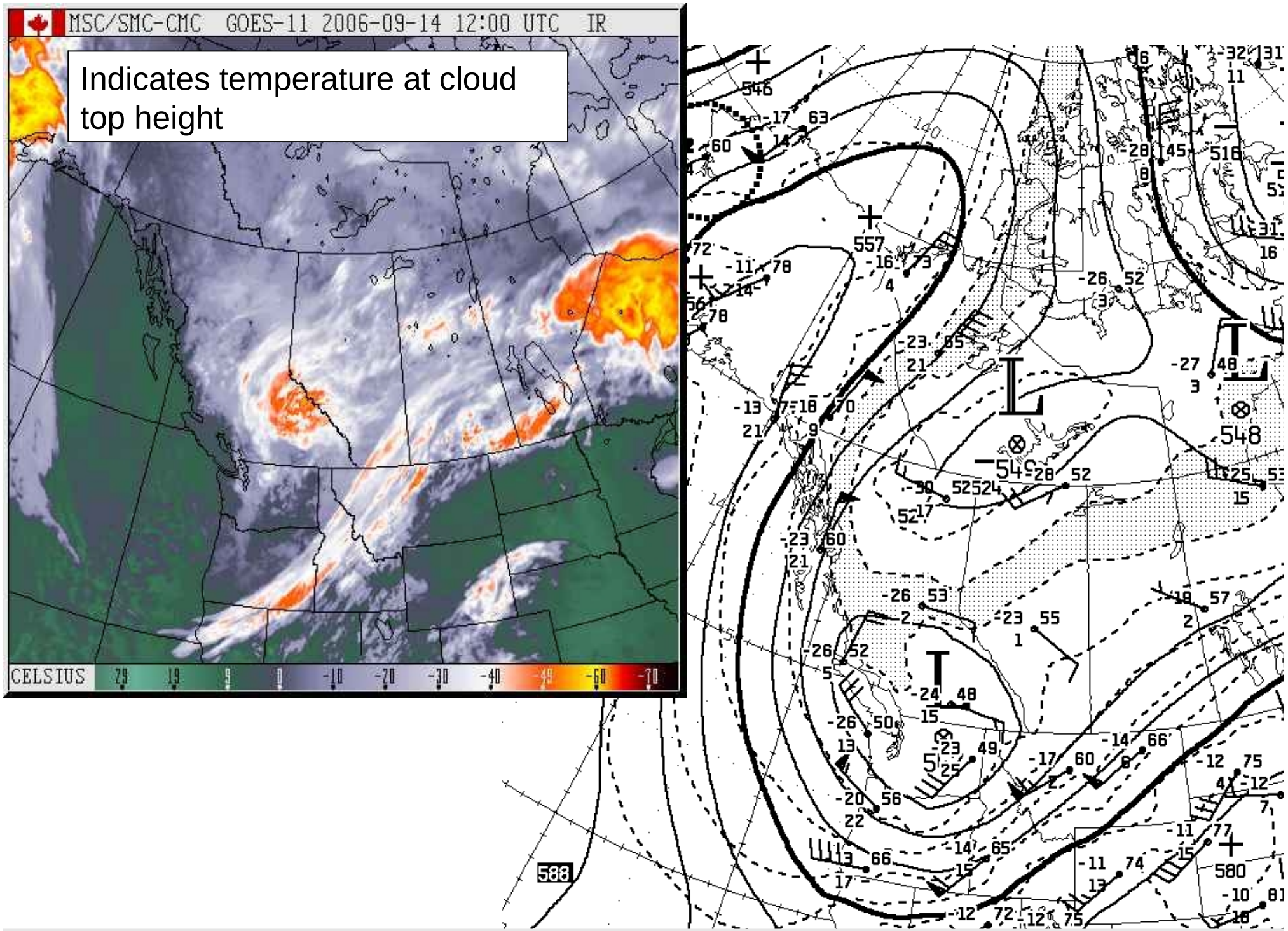


Products, Resolution, and Accuracy

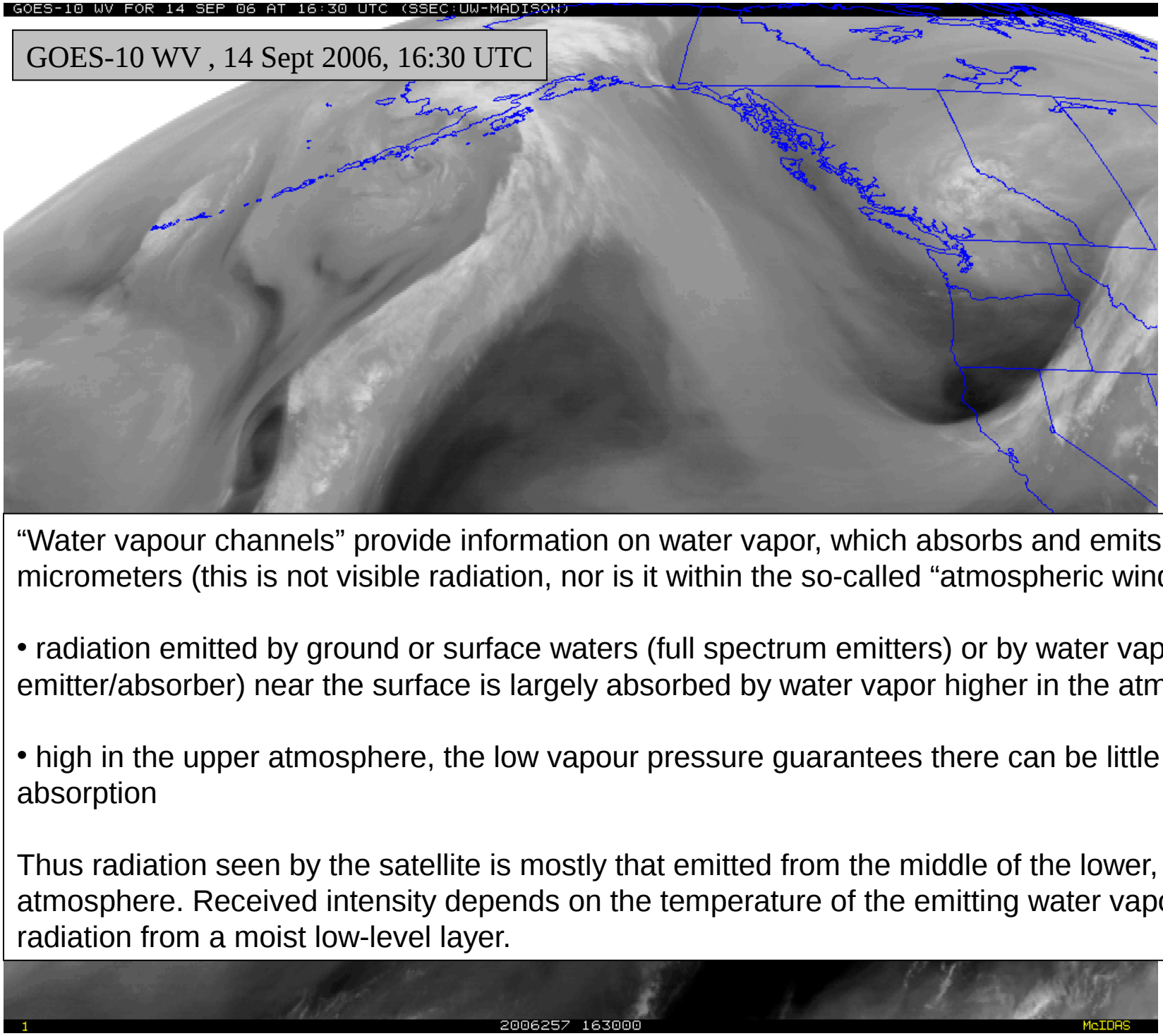
Product	Resolution (km) Vertical	Resolution (km) Horizontal	Accuracy Absolute	Accuracy Relative
Temperature				
Profile	3-5	50	2-3 K	1 K
Land	---	10	2 K	1 K
Sea	---	10	1 K	0.5 K
Moisture				
Profile	2-4	50	30%	20%
Total	---	10	20%	10%
Motion	3 layers	50	6 m/sec	3 m/sec
Cloud				
Height	2 layers	10	50 mb	25 mb
Amount	total	10	15%	5%
Ozone*				
Total	---	50	30%	15%
Motion	1 layer	50	10 m/sec	5 m/sec
IR Flux*	total	50	10 W/m^2	3 W/m^2



CMC 500 hPa analysis, 14 Sept 2006, 12 UTC



CMC 500 hPa analysis, 14 Sept 2006, 12 UTC

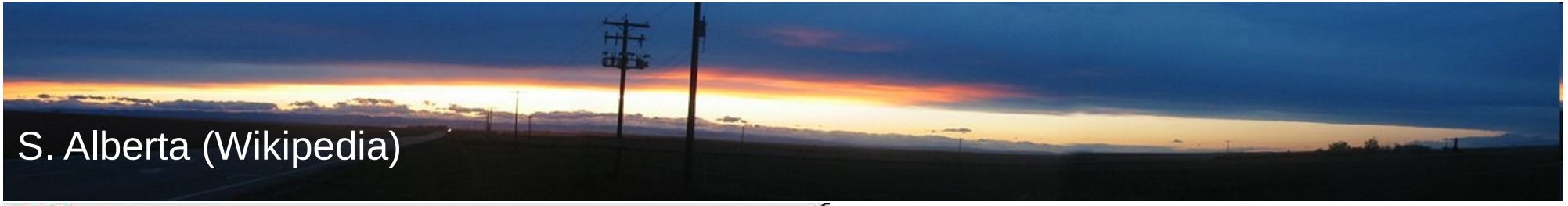


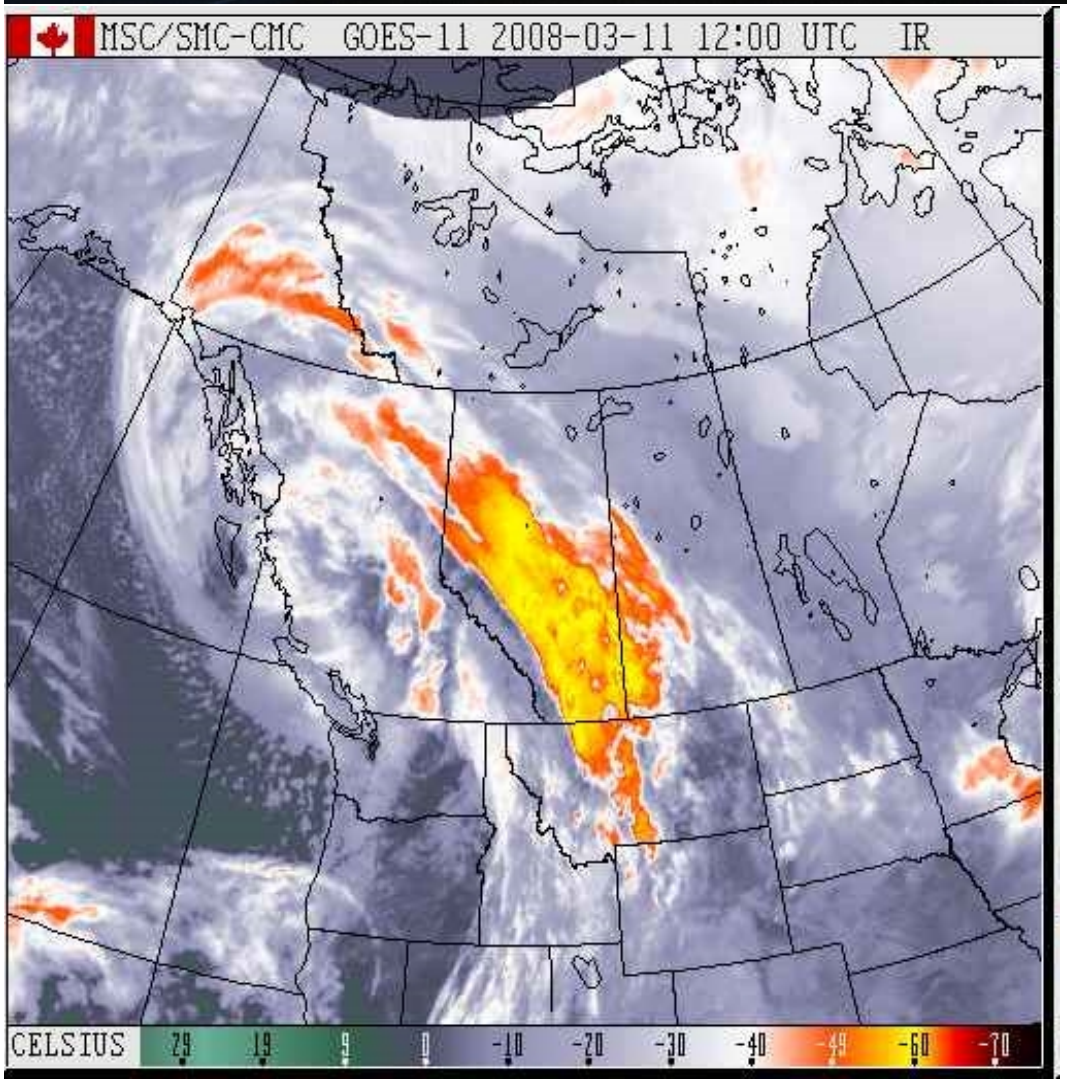
"Water vapour channels" provide information on water vapor, which absorbs and emits at about 6.3 micrometers (this is not visible radiation, nor is it within the so-called "atmospheric window")

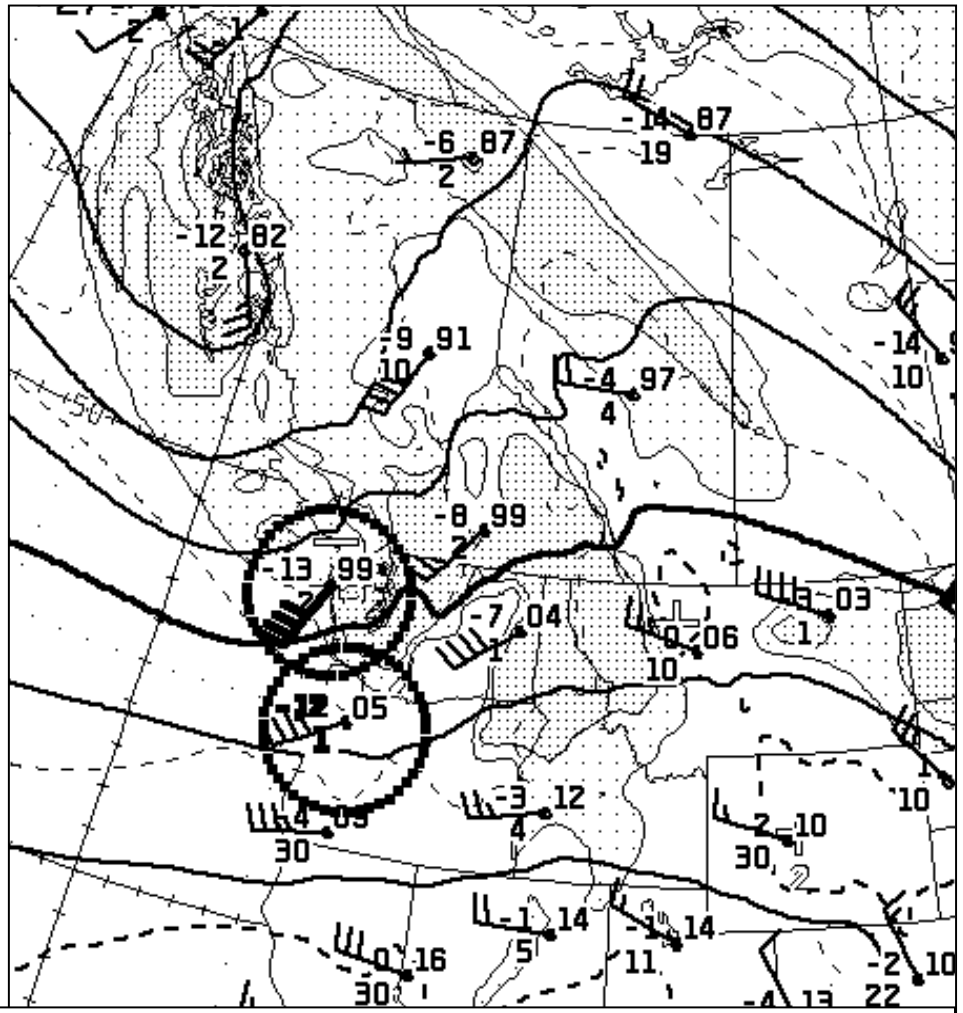
• radiation emitted by ground or surface waters (full spectrum emitters) or by water vapor (selective emitter/absorber) near the surface is largely absorbed by water vapor higher in the atmosphere

• high in the upper atmosphere, the low vapour pressure guarantees there can be little emission or absorption

Thus radiation seen by the satellite is mostly that emitted from the middle of the lower, moist layer of the atmosphere. Received intensity depends on the temperature of the emitting water vapour: strong radiation from a moist low-level layer.



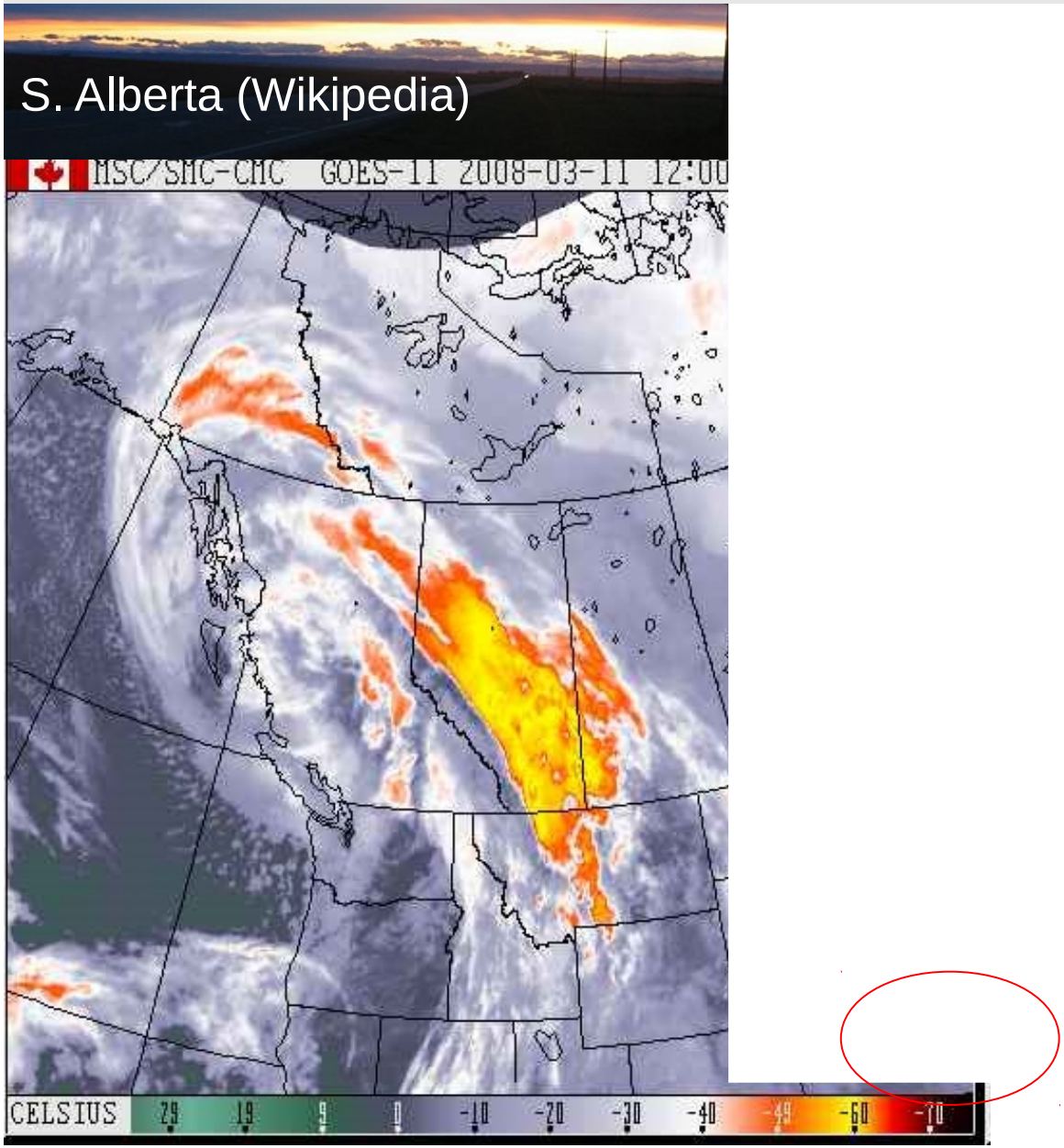




700 hPa analysis 12 UTC 2008-03-11

- dry slot in lee of Rockies – sinking air
- Chinook arch

Exercise: determine cloud top height over C. Alberta



- dry slot in lee of Rockies
- Chinook arch
- cloud top over

Diagnosing cloud type from satellite image

Stratiform clouds

- smooth texture, sharp edges (perhaps defined by topography)
- low stratiform clouds (stratus, stratocumulus) relatively warm – ir image is dull; may be very white on the vis, provided they are thick

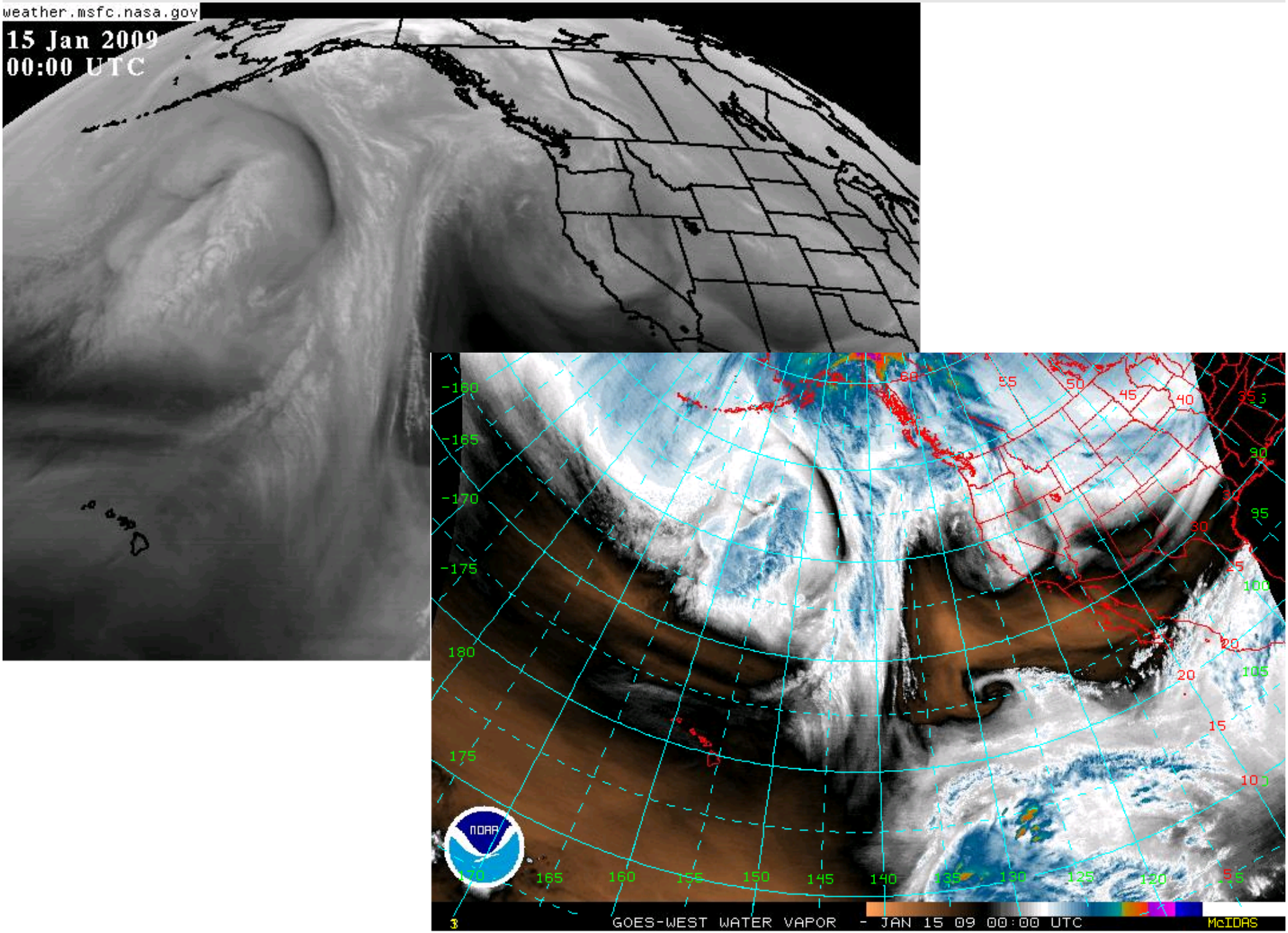
Cumuliform clouds

- stratocumulus: often arranged in sheets, lines or streets, esp. over water in winter; as a low cloud they will be dull/dark on the ir photo, but if thick enough bright and lumpy on the vis
- towering Cu or Cumulonimbus: bright on vis and ir; lumpy/shadowed on the vis

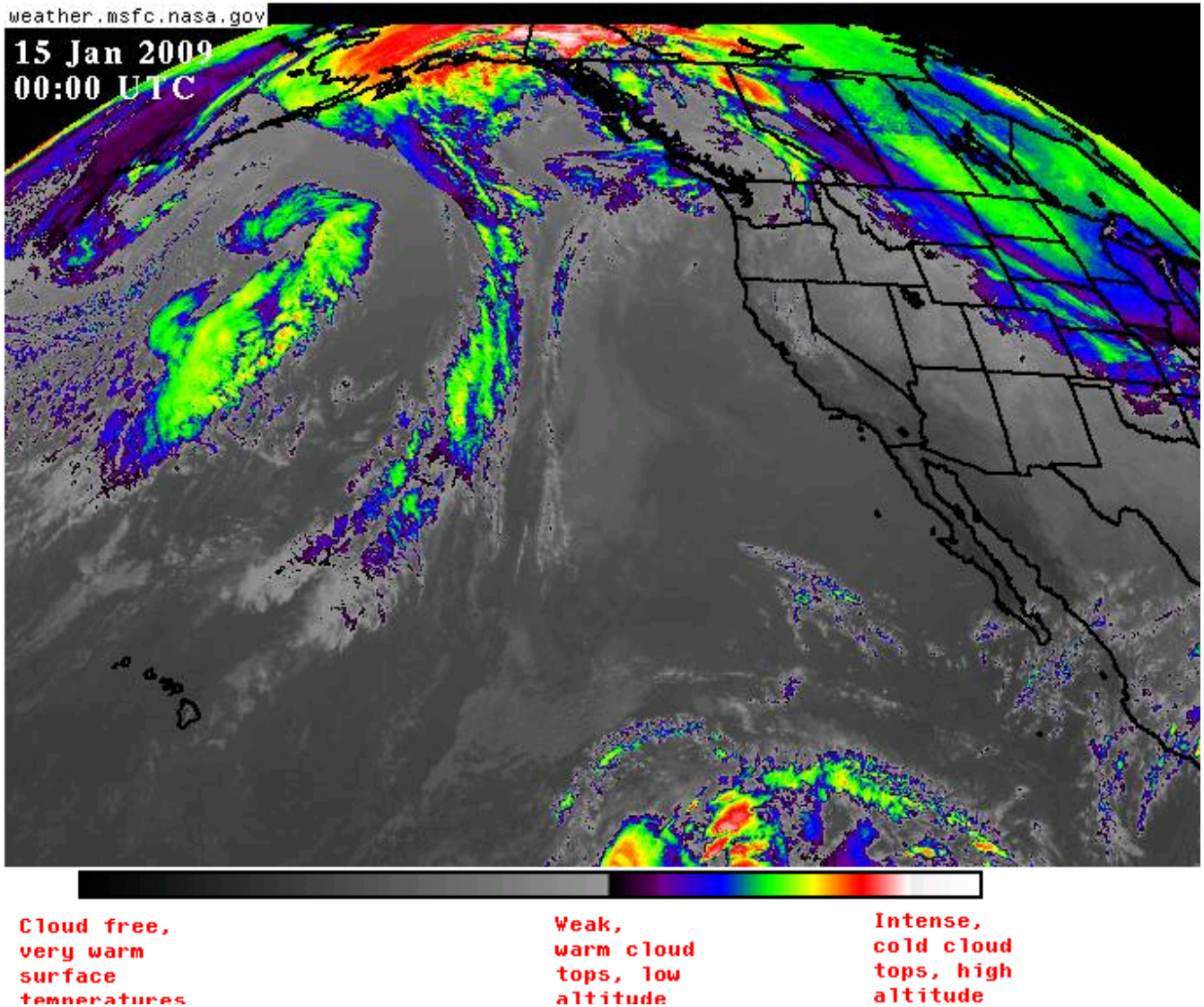
High level (cirro) clouds

- being high, thick cirrus clouds will show high & cold (bright red/yellow) on the ir
- cirrus – fibrous appearance
- cirrocumulus – cellular
- cirrostratus – uniform

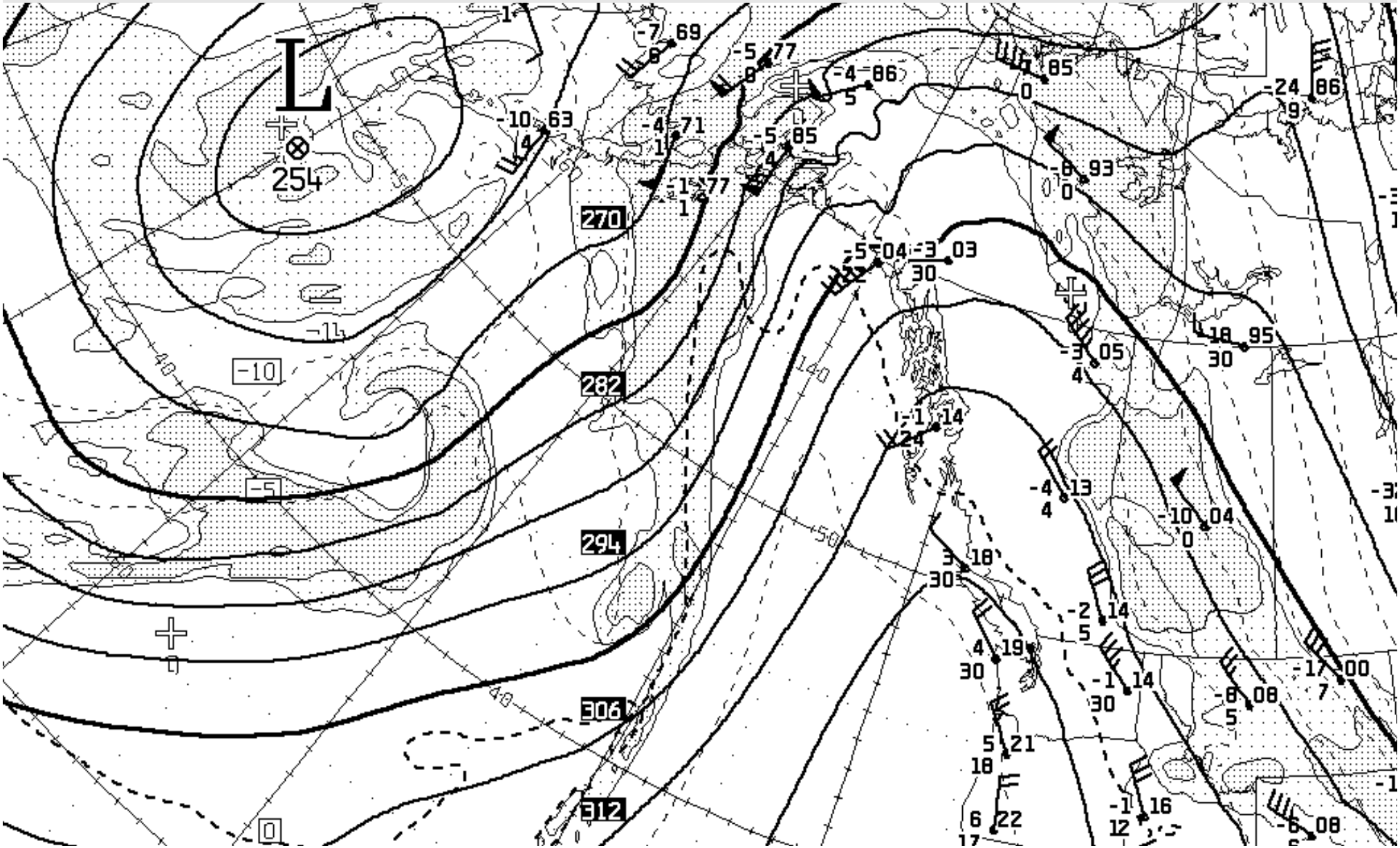
Compare initial state of CMC & NMC models with GOES west wv



Compare initial state of CMC & NMC models with GOES west ir



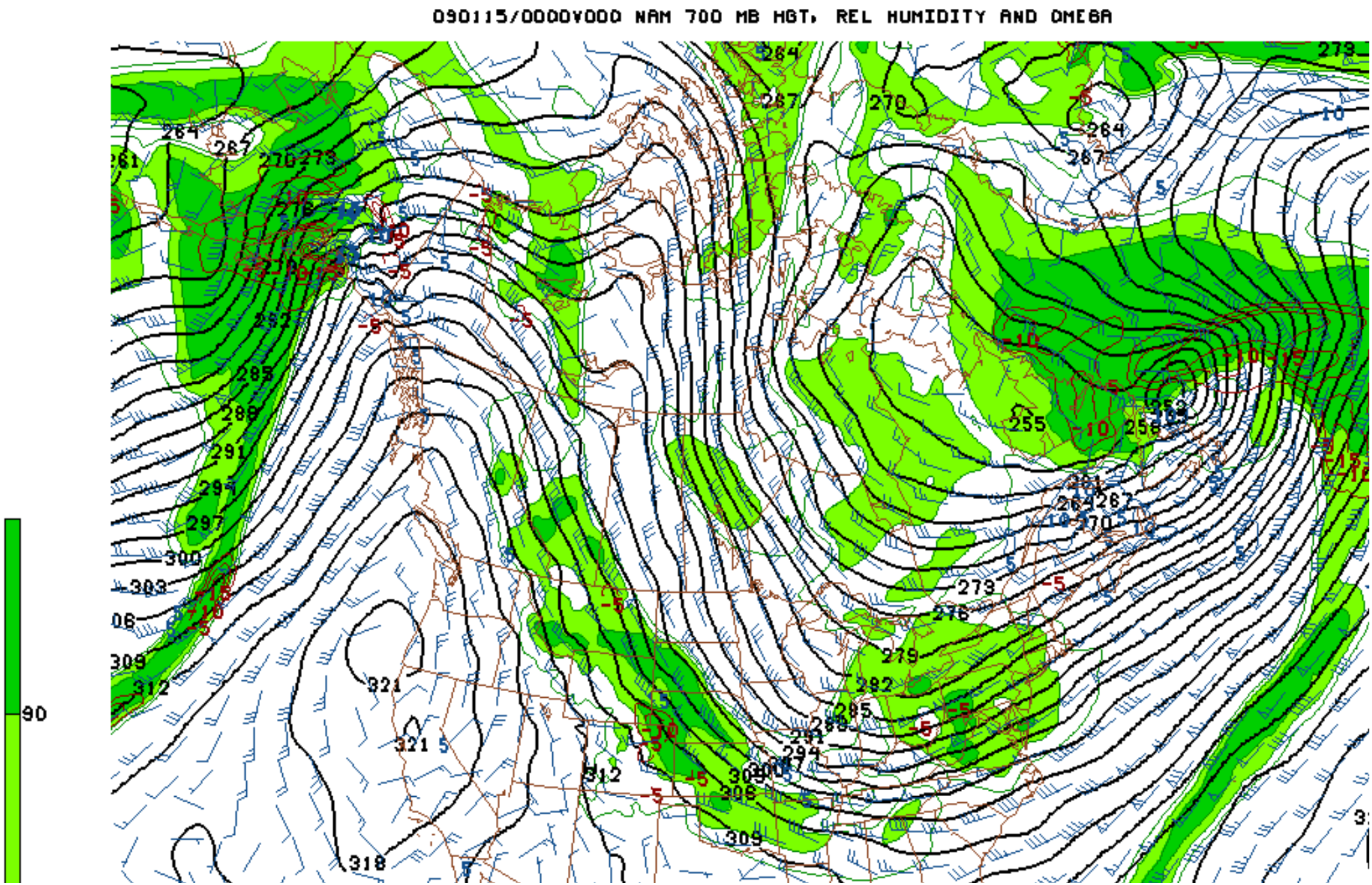
Compare initial state of CMC model with GOES west



Compare humidity featureswith the satellite images

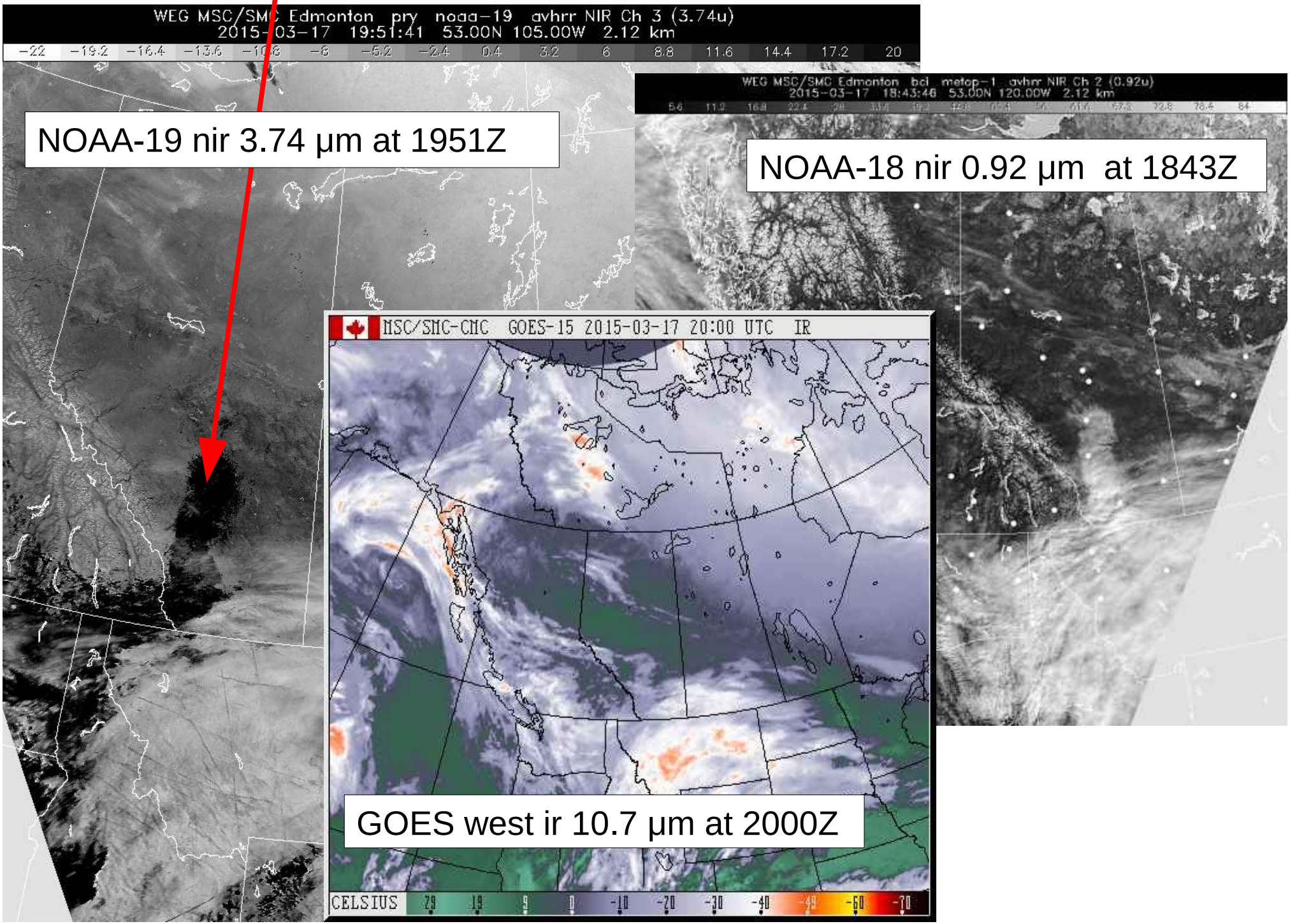
CMC 00h prog (i.e. analysis) valid 00 UTC Thurs 15 Jan. 2009

Compare initial state of NAM model with GOES west

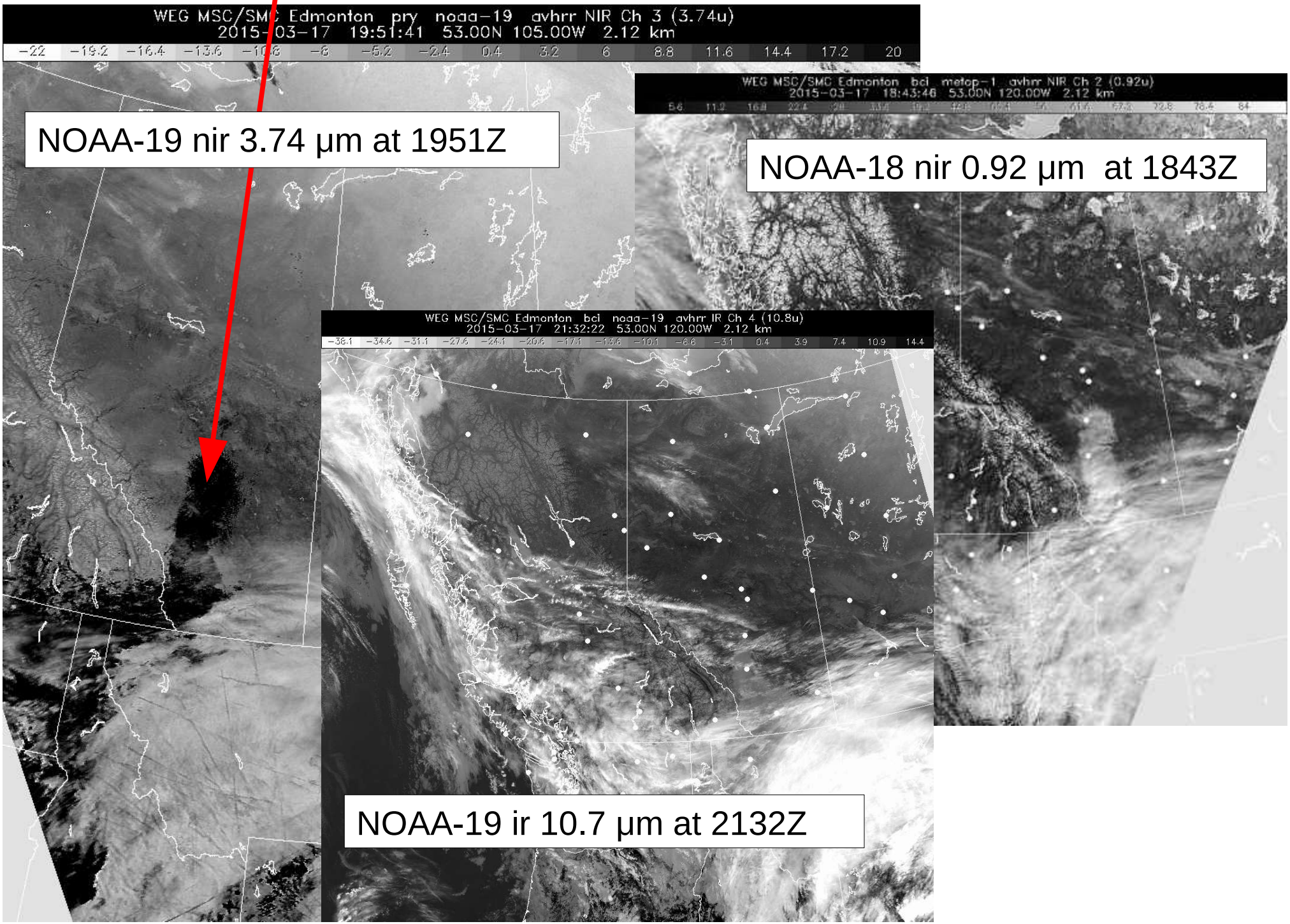


NAM 00h prog (i.e. analysis) valid 00 UTC Thurs 15 Jan. 2009

Puzzle: what is this feature?



Puzzle: what is this feature?



Conclusion:

- satellite remote sensing an essential element of numerical weather prediction
- satellite radiance field is assimilated to help define the initial state of the atmos.
- to the forecast interpreter, satellite images
    - permit to see “real world” in real time
    - resolve detail finer than model analysis (might be critical for forecasts in sparsely populated areas)
    - permit to get a sense of whether what s/he sees outside the window is local or widespread