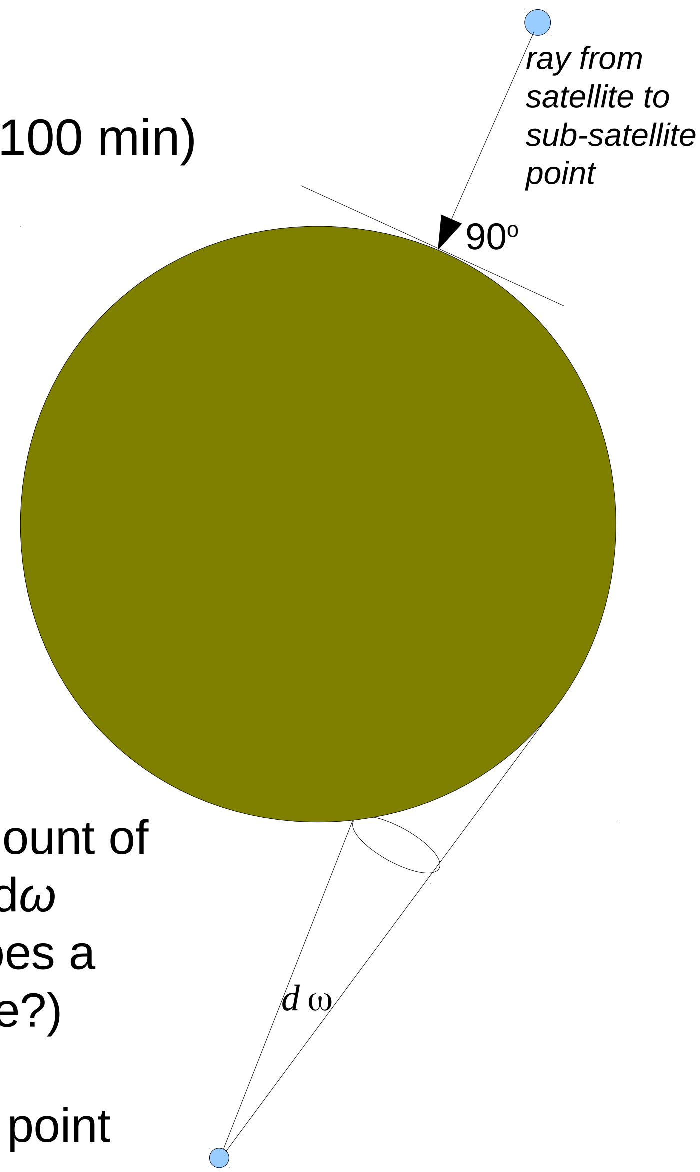
Satellite Remote Sensing & Operational Meteorology

- 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

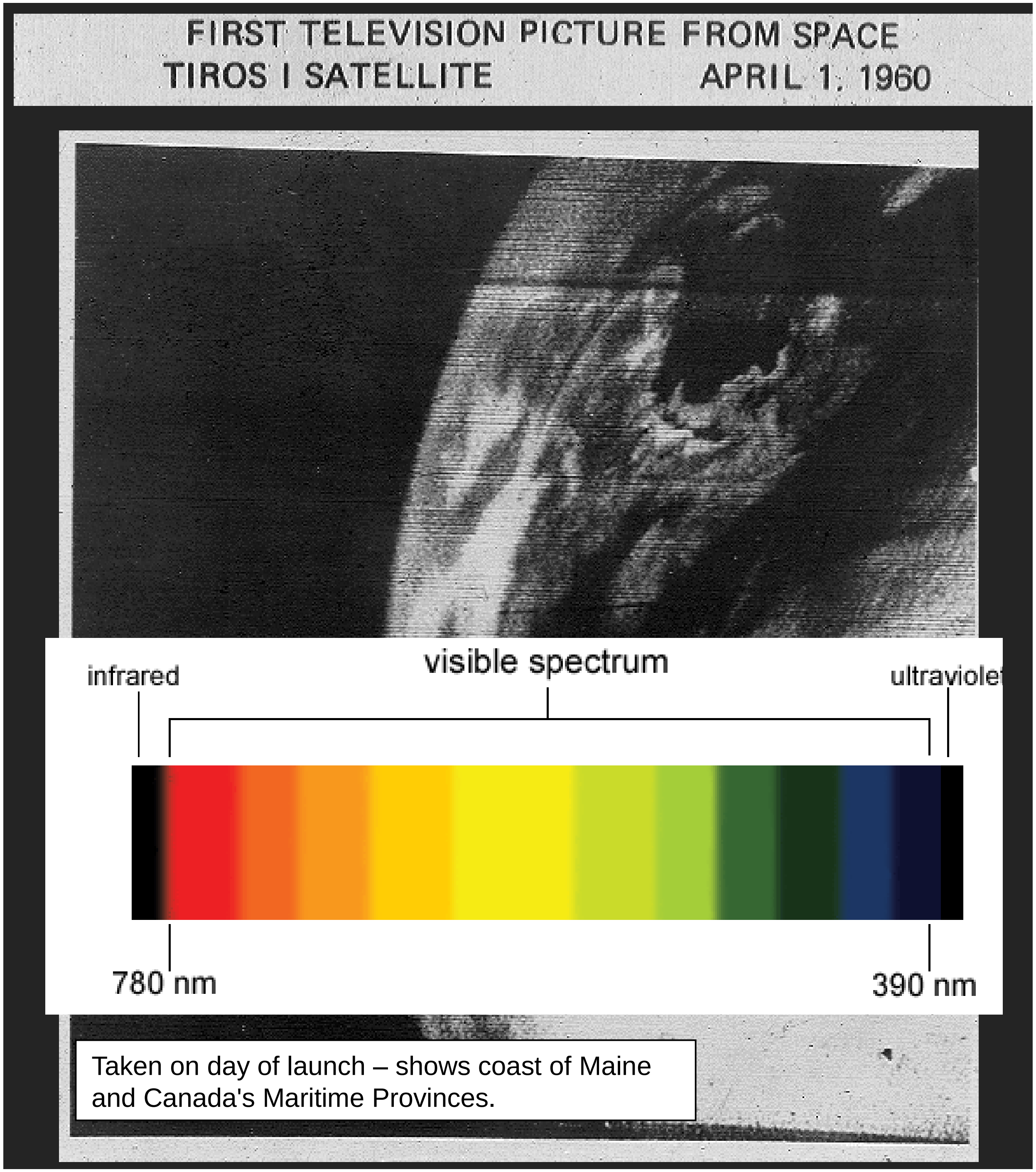
- daytime only; whiteness of each pixel proportional to the amount of visible radiation received by the satellite from the solid angle dω subtended by the pixel at the detector (Q: what solid angle does a sphere subtend at its centre? What are the units of solid angle?)

- relative positions of the sub-solar point and the sub-satellite point influence the image (eg. if satellite is directly overhead from the subsolar point P, the image at point P would display no shadows)

- distinctions in albedo (shortwave reflectivity) distinguish features

eas372_satellitemeteorology.odp
JDW, EAS, U. Alberta
Last mod. 21 Mar., 2017

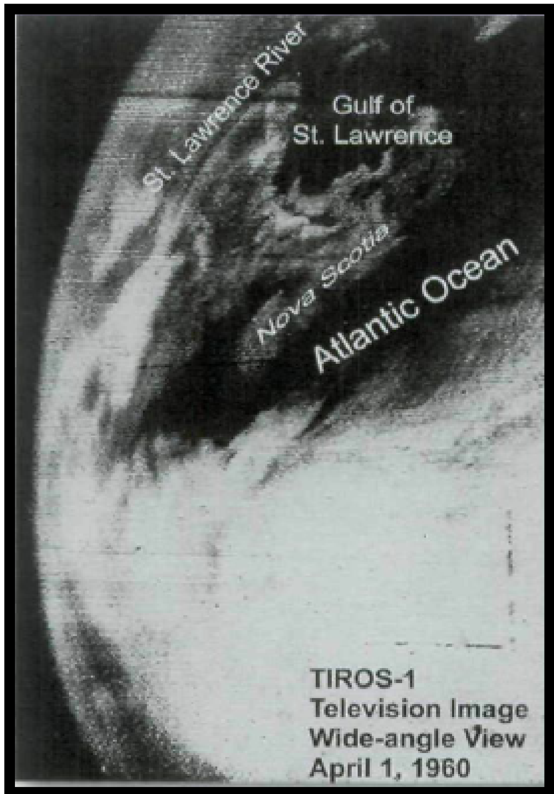
TIROS



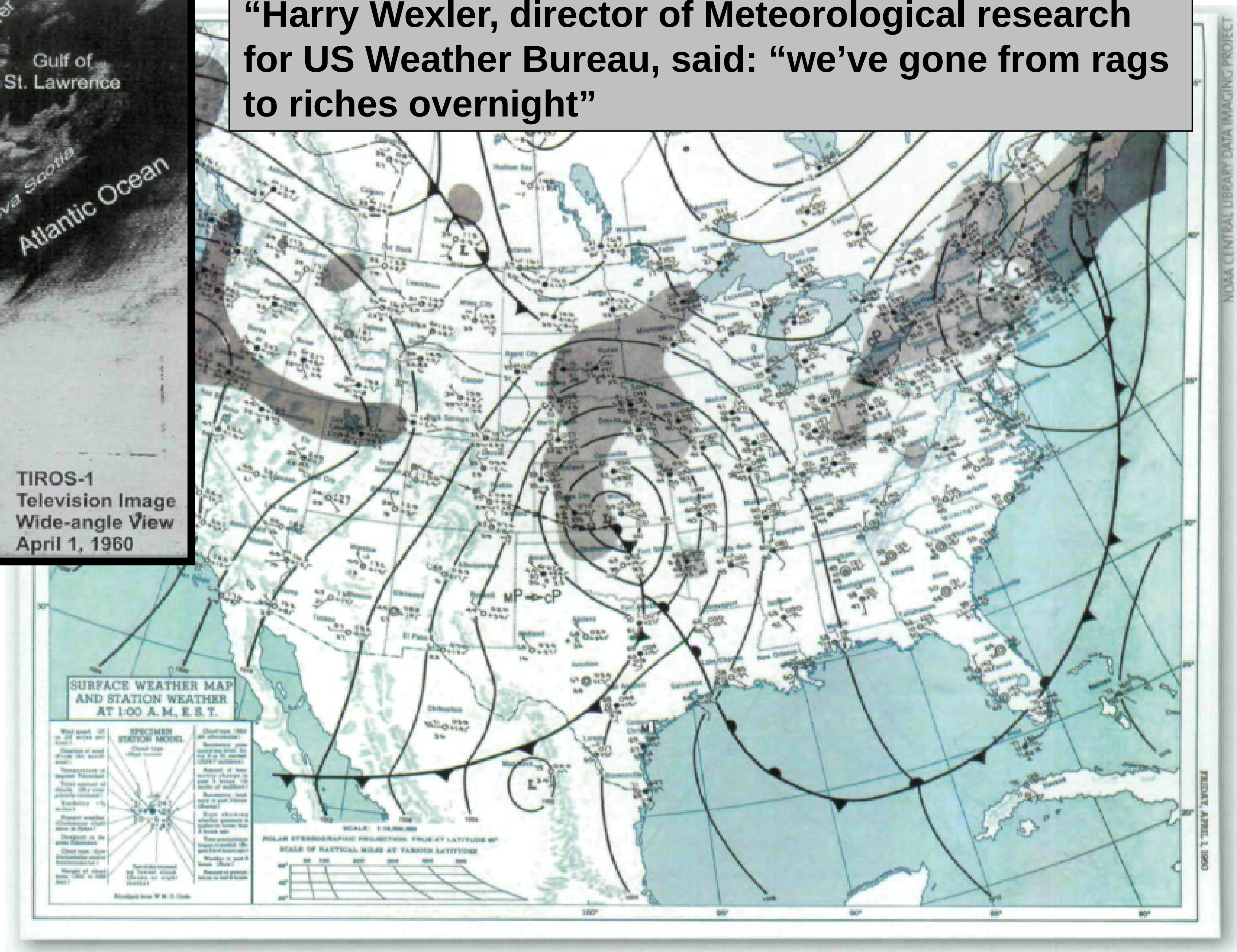
Taken on day of launch – shows coast of Maine and Canada's Maritime Provinces.

- first “Television InfraRed Observation Satellite”
- nearly 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
- 6Feb/09, launch of NOAA-19, 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/NOAA 20 will launch in 2017

from S. Potter (2006, Weatherwise: "April 1, 1960")



"Harry Wexler, director of Meteorological research for US Weather Bureau, said: "we've gone from rags to riches overnight"



U.S. Weather Bureau Daily Weather Map for 1:00 a.m. EST, April 1, 1960. A cold front extends south from an area of low pressure centered over New England and becomes stationary as it joins with a warm front ahead of a storm system in the Midwest. Behind this front is an area of high pressure, which provided relatively calm conditions for the launch of the world's first successful weather satellite, TIROS I.

Orbit of geostationary satellite

An equilibrium orbit at height *h* above earth's surface results provided that earth's gravitational pull on the satellite provides the needed centripetal acceleration of the satellite, 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 $G = 6.673 \times 10^{-11}$ [$N\ m^2\ kg^{-2}$]
- earth's mass $M_e = 5.98 \times 10^{24}$ kg
- earth's radius $R_e = 6.368 \times 10^6$ m
- *V* is the linear velocity of the satellite
- angular velocity of the satellite

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

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

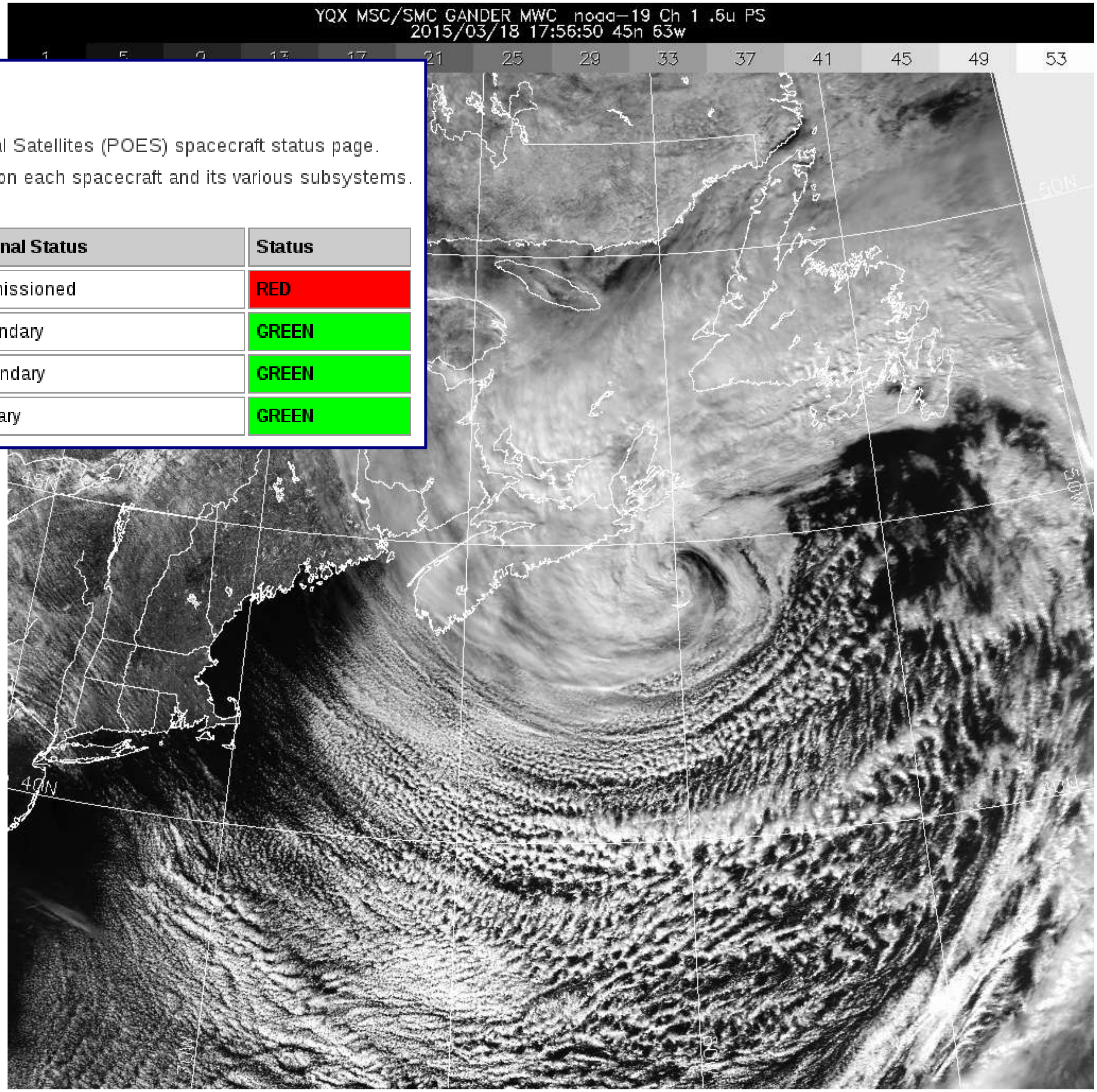
Exercise: compute the orbital period of NOAA-18, with altitude h = 870 km

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

- $G = 6.673 \times 10^{-11}$ [N m^2 kg^{-2}]
- $M_e = 5.98 \times 10^{24}$ kg
- $R_e = 6.368 \times 10^{6}$ 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 vis. 1.6 µm (nir)   18Z Wed. 18 March 2015



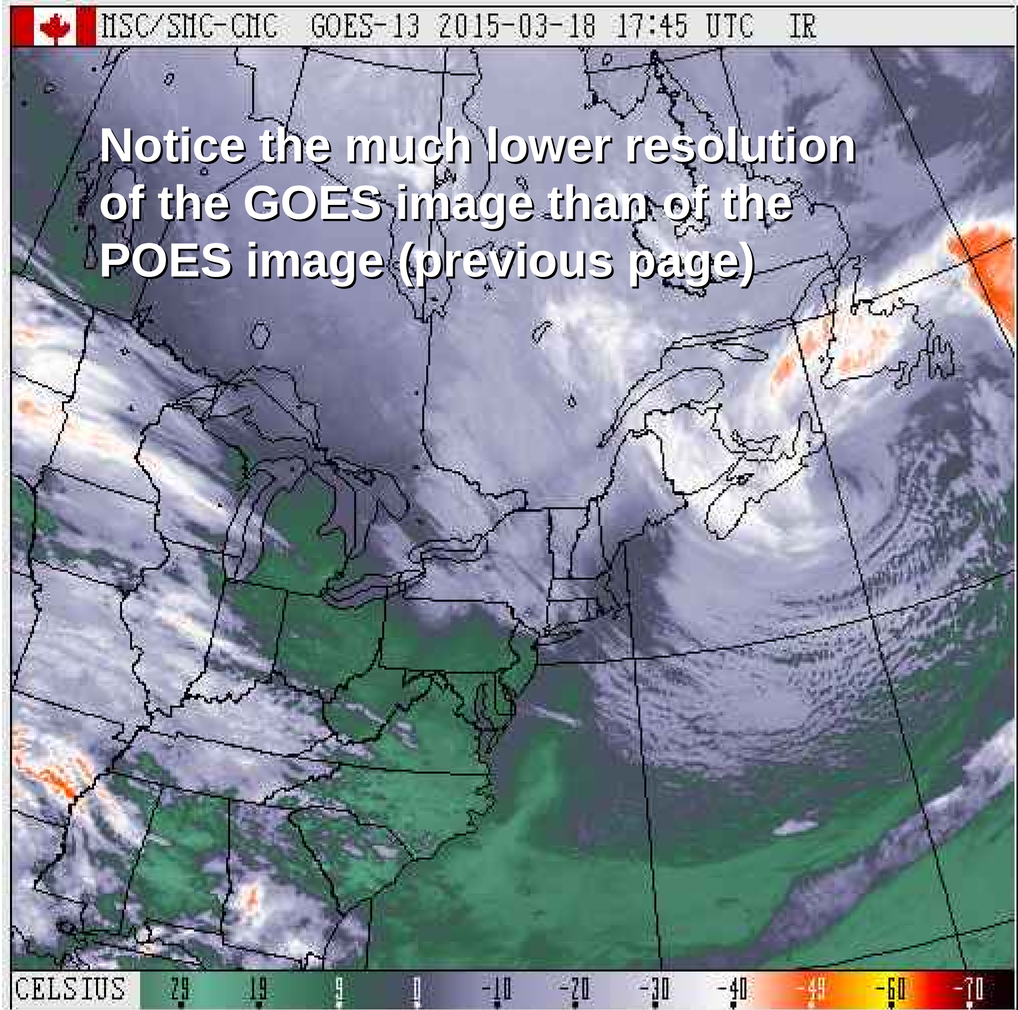
POES Operational Status

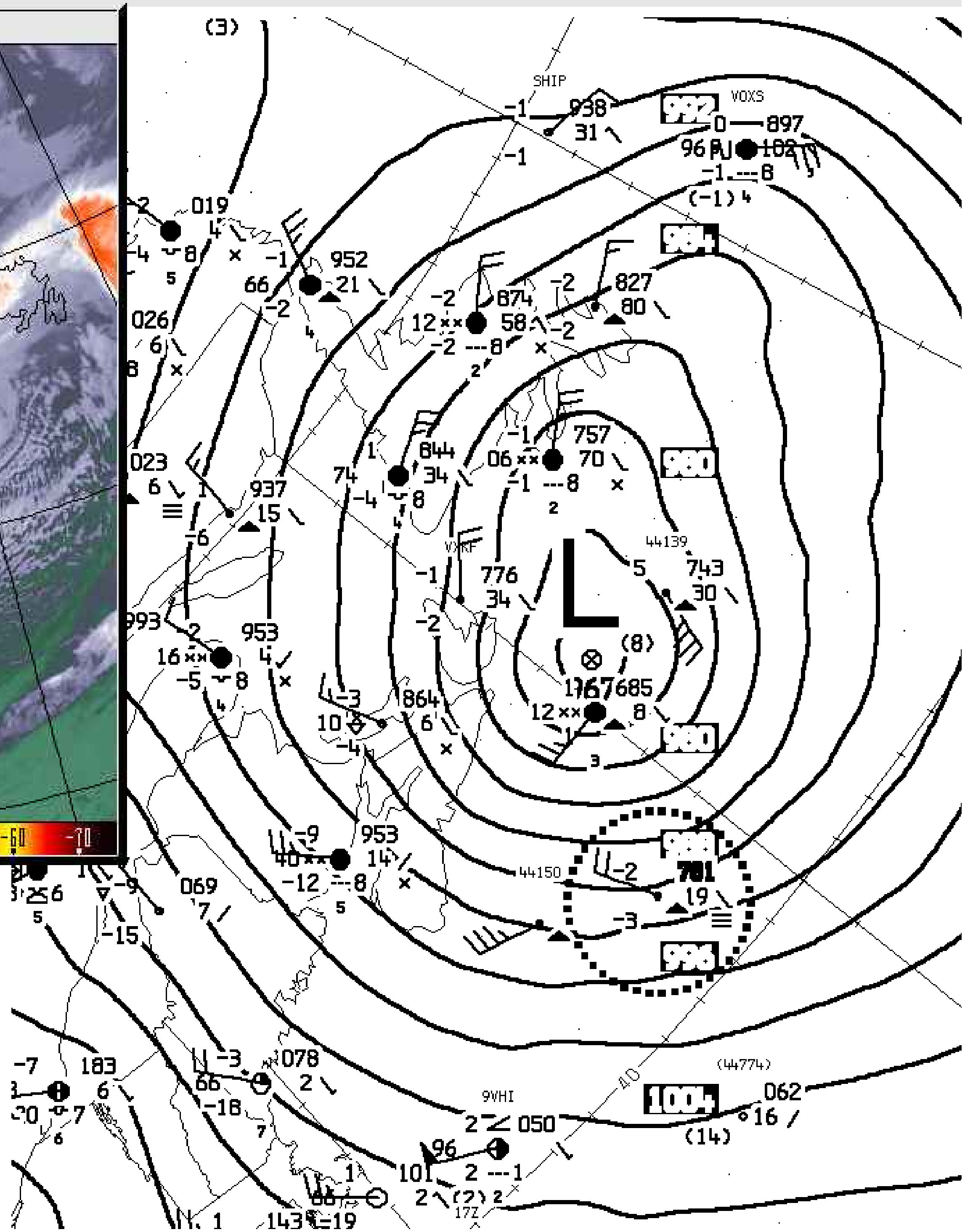
Welcome to the Polar Operational Environmental Satellites (POES) spacecraft status page.
This site provides up to date status information on each spacecraft and its various subsystems.

Spacecraft	Operational Status	Status
NOAA-11, -12, -14, -16, -17	Decommissioned	RED
NOAA-15	AM Secondary	GREEN
NOAA-18	PM Secondary	GREEN
NOAA-19	PM Primary	GREEN

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)





GOES Operational Status

Welcome to the Geostationary Operational Environmental Satellites (GOES) spacecraft status page. This site provides up to date status information on each spacecraft and its various subsystems.

Spacecraft	Operational Status	Status
GOES-8 to 12	De-commissioned	RED
GOES 13	Operational East	GREEN
GOES 14	On-Orbit Storage	GREEN
GOES 15	Operational West	GREEN

NOAA's GOES and POES satellites

GOES P is GOES-15, present GOES-west

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

GOES-West

GOES 15 Spacecraft Status Summary

Spacecraft Letter: P
Launch Date: 03/04/2010
Spacecraft Location: 135.0 West
Operational Date: 12/06/2011
AOCS Mode: Normal Upright
Operational Status: Operation West
Notes: GOES-15 arrived 135.0W on 12/14/2011.

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-East

GOES 13 Spacecraft Status Summary

Spacecraft Letter: N
Launch Date: 05/24/2006
Spacecraft Location: 75 West
Operational Date: 04/14/2010
ACS Mode: Normal Upright
Operational Status: Operation East
Notes: GOES-13 resumed GOES-East services at 1445z on October 18, 2012.

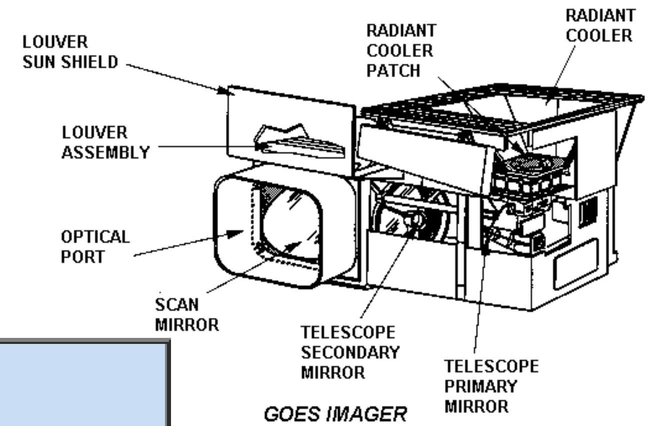
Subsystem Status:

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

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

- techniques are "passive"

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

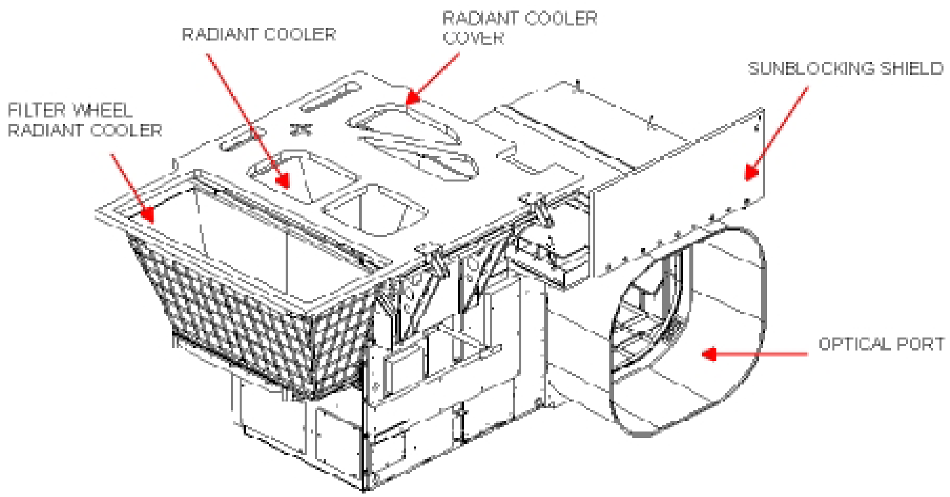


Imager Instrument Characteristics (GOES I-M)					
Channel number:	1 (Visible)	2 (Shortwave)	3 (Moisture)	4 (IR 1)	5 (IR 2)
Wavelength range (um)	0.55 - 0.75	3.80 - 4.00	6.50 - 7.00	10.20 - 11.20	11.50 - 12.50
Instantaneous Geographic Field of View (IGFOV) at nadir	1 km	("near ir") 4 km	8 km	4 km	4 km
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				

"nadir" refers to the point on earth's surface at which a beam emitted from the satellite would strike earth's local tangent plane at perpendicular angle of incidence, i.e., at the sub-satellite point

"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"

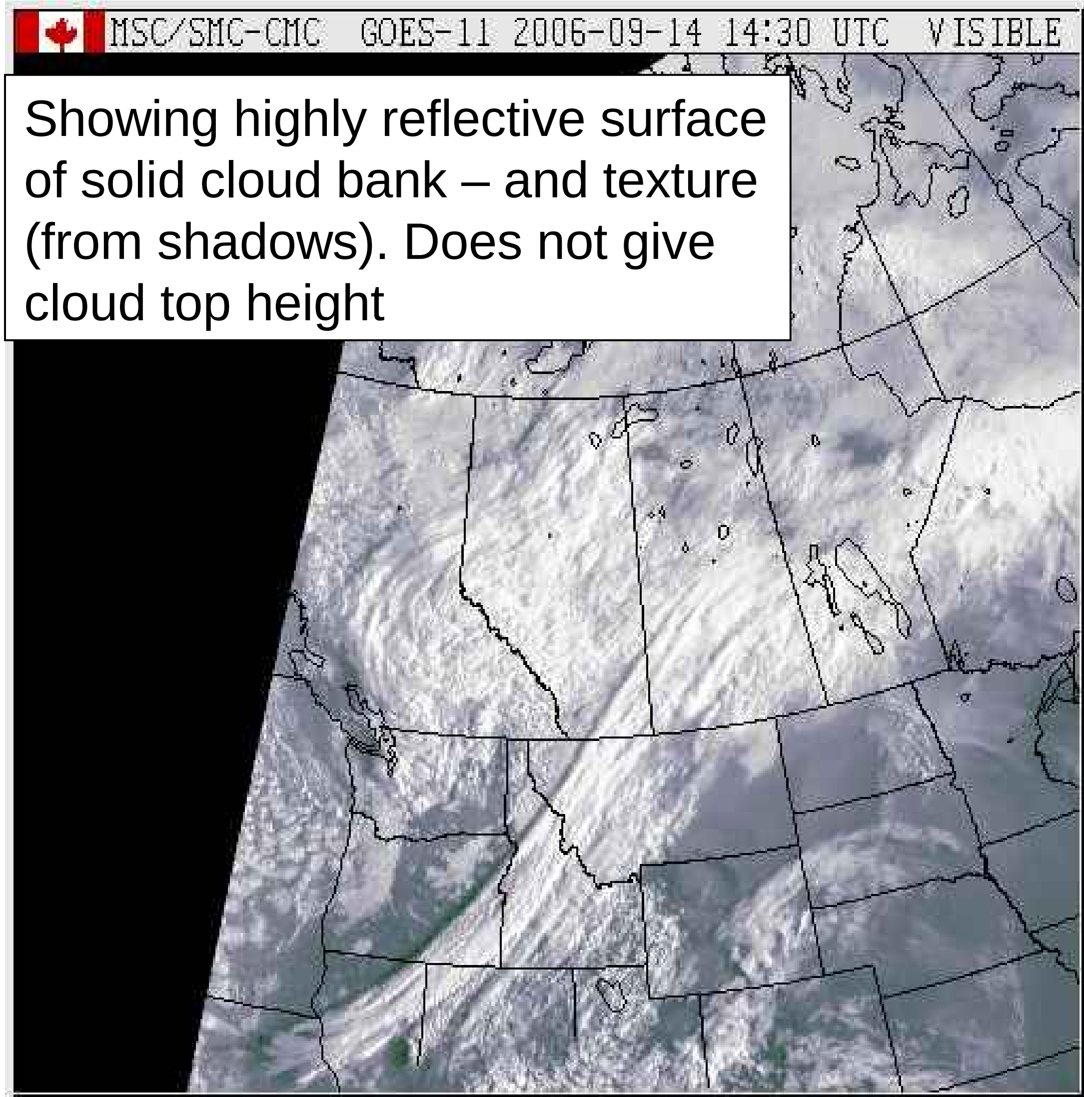
GOES N-P Sounder

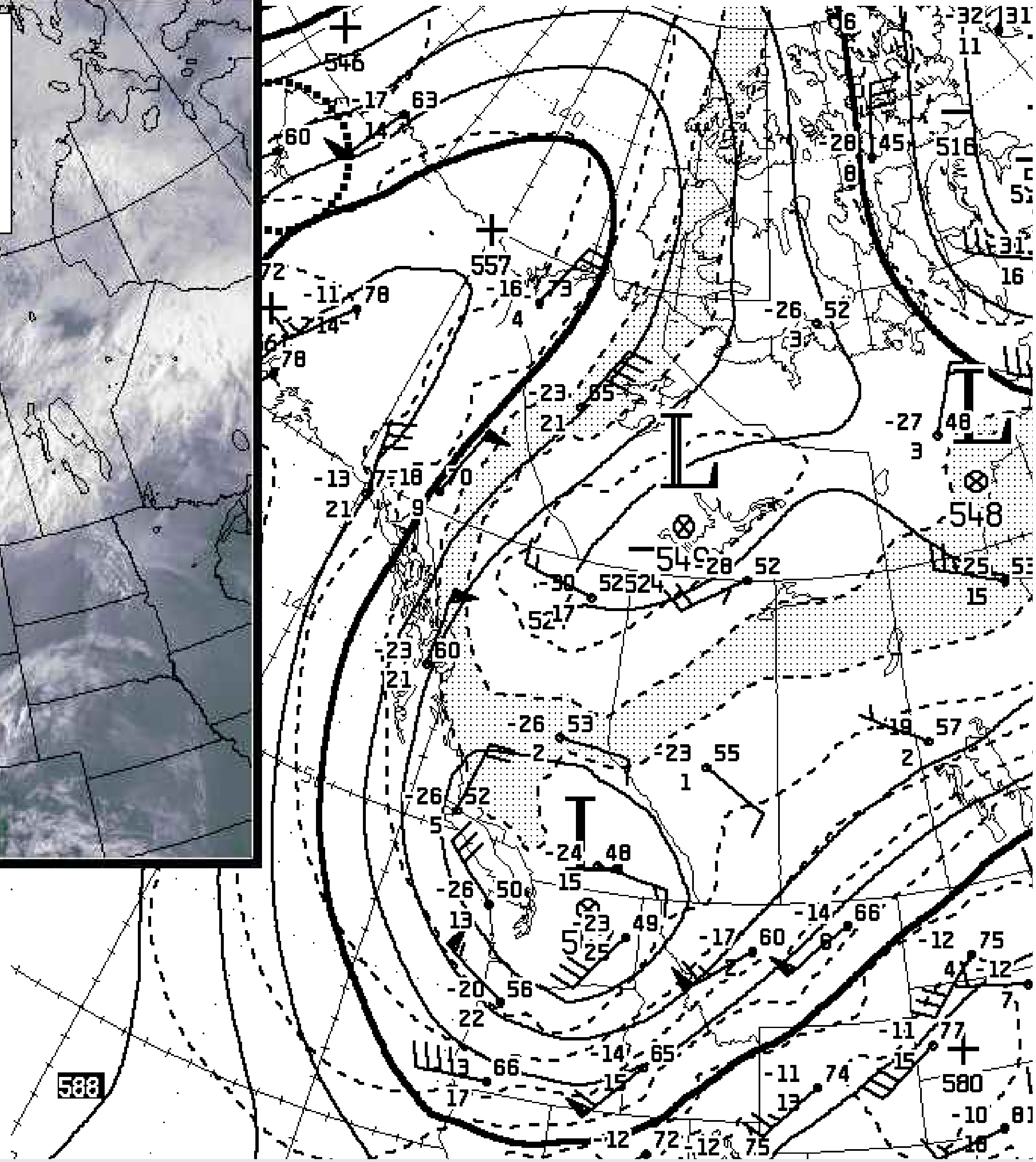


Products, Resolution, and Accuracy

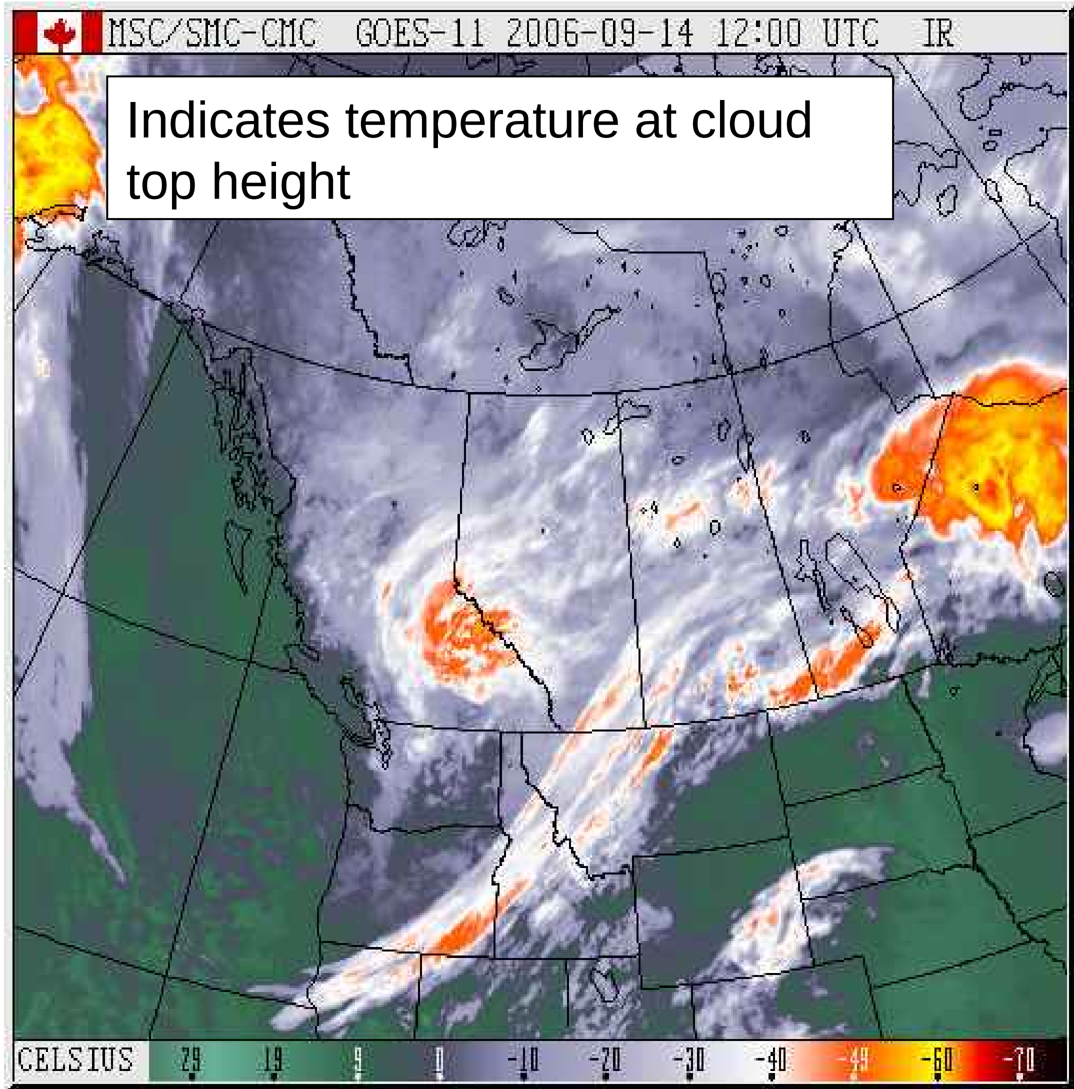
Product	Resolution (km) Vertical	Resolution (km) Horizontal	Accuracy Absolute	Accuracy Relative
Temperature				
Profile	3-5	50	2-3 K	1 K
Land	---	10	2 K	1 K
Sea	---	10	1 K	0.5 K
Moisture				
Profile	2-4	50	30%	20%
Total	---	10	20%	10%
Motion	3 layers	50	6 m/sec	3 m/sec
Cloud				
Height	2 layers	10	50 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

Showing highly reflective surface of solid cloud bank – and texture (from shadows). Does not give cloud top height

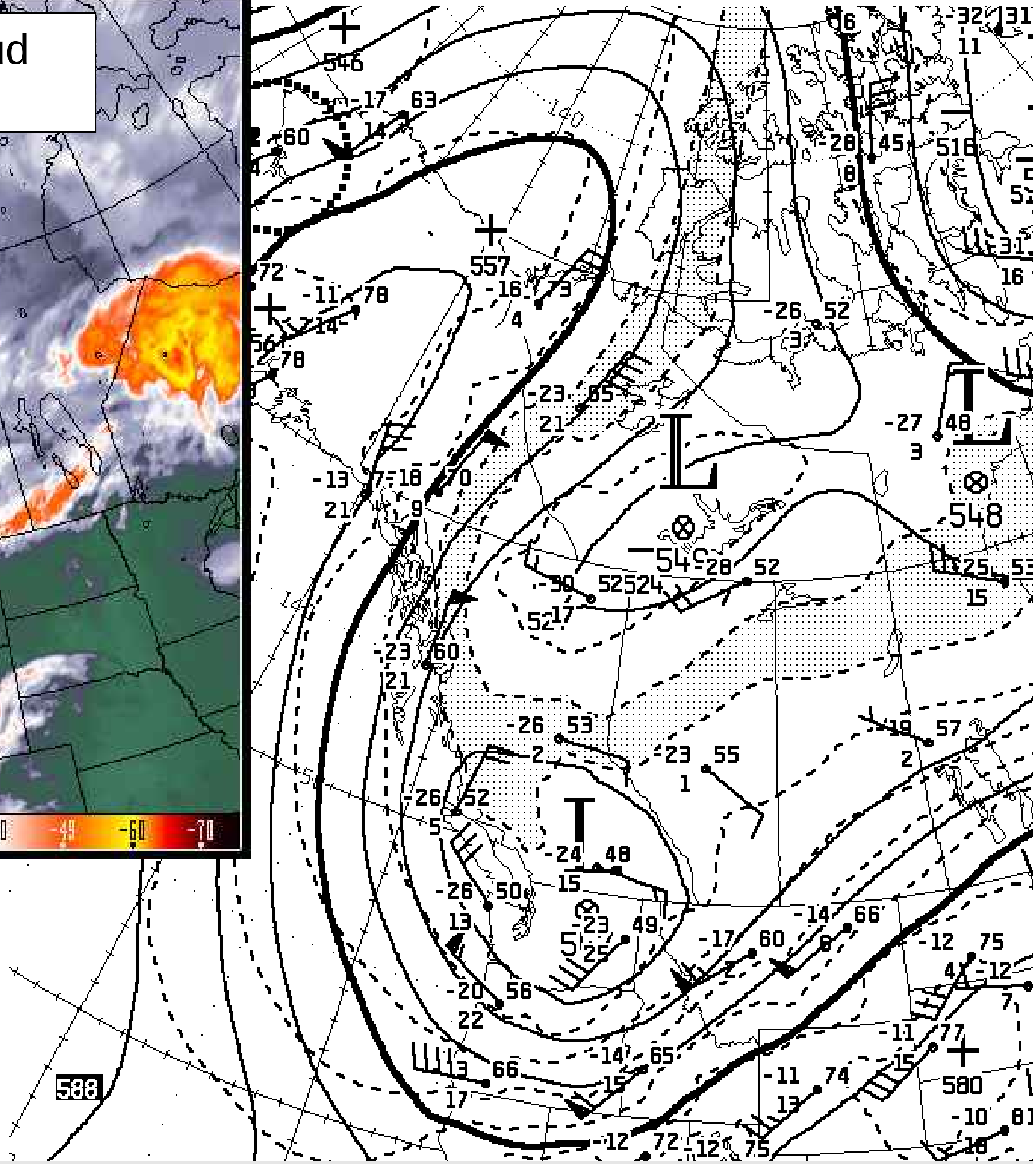




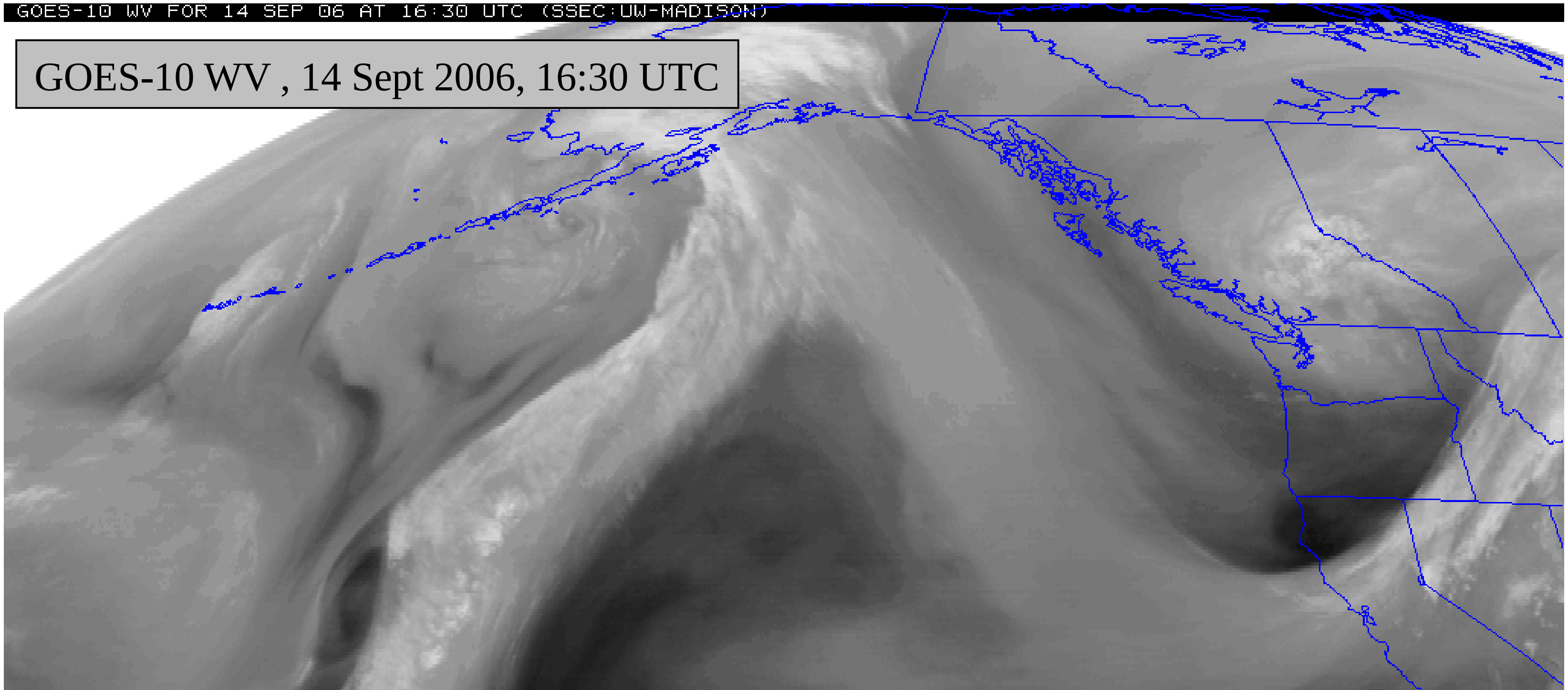
CMC 500 hPa analysis, 14 Sept 2006, 12 UTC



Indicates temperature at cloud top height



CMC 500 hPa analysis, 14 Sept 2006, 12 UTC



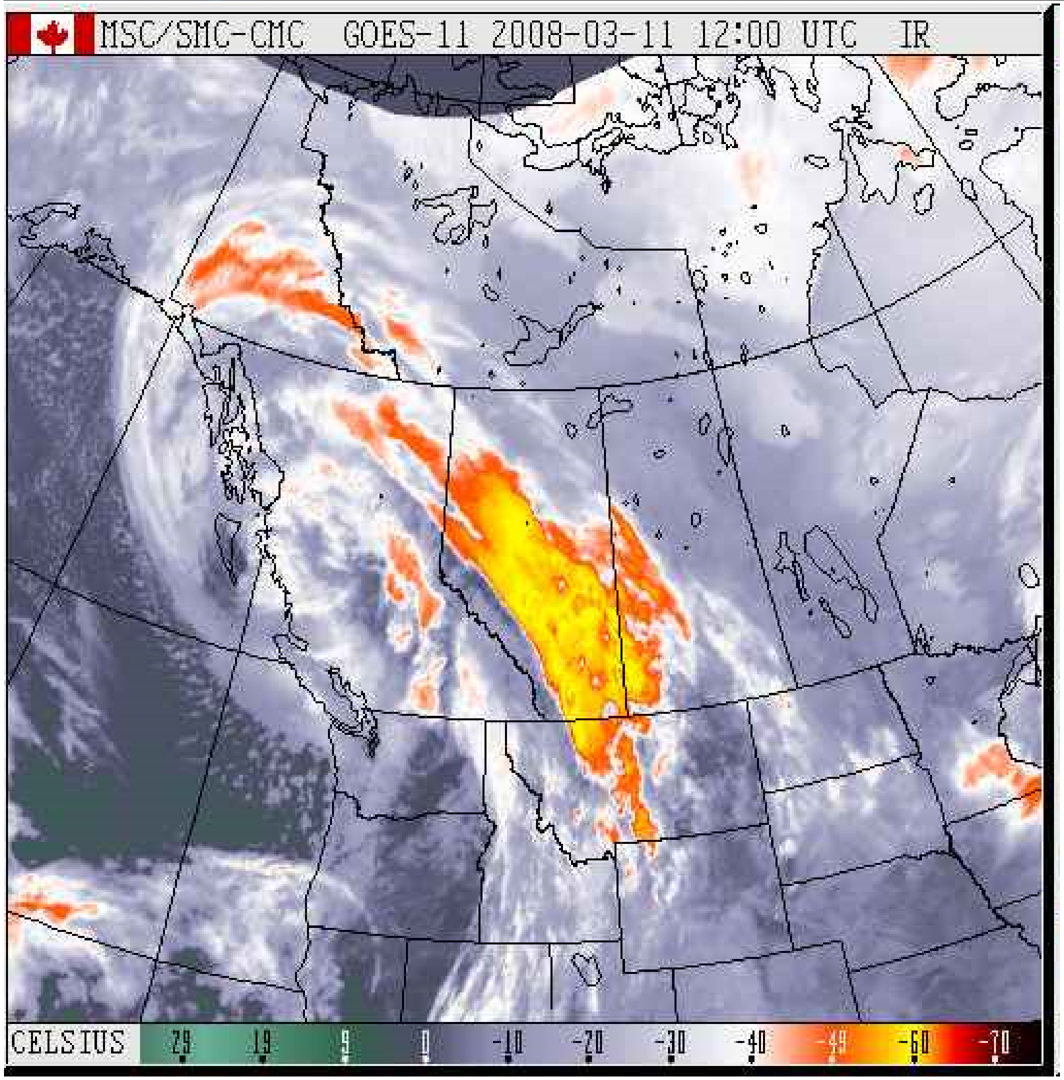
“Water vapour channels” provide information on water vapor, which absorbs and emits at about 6.3 micrometers (this is not visible radiation, nor is it within the so-called “atmospheric window“)

- 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

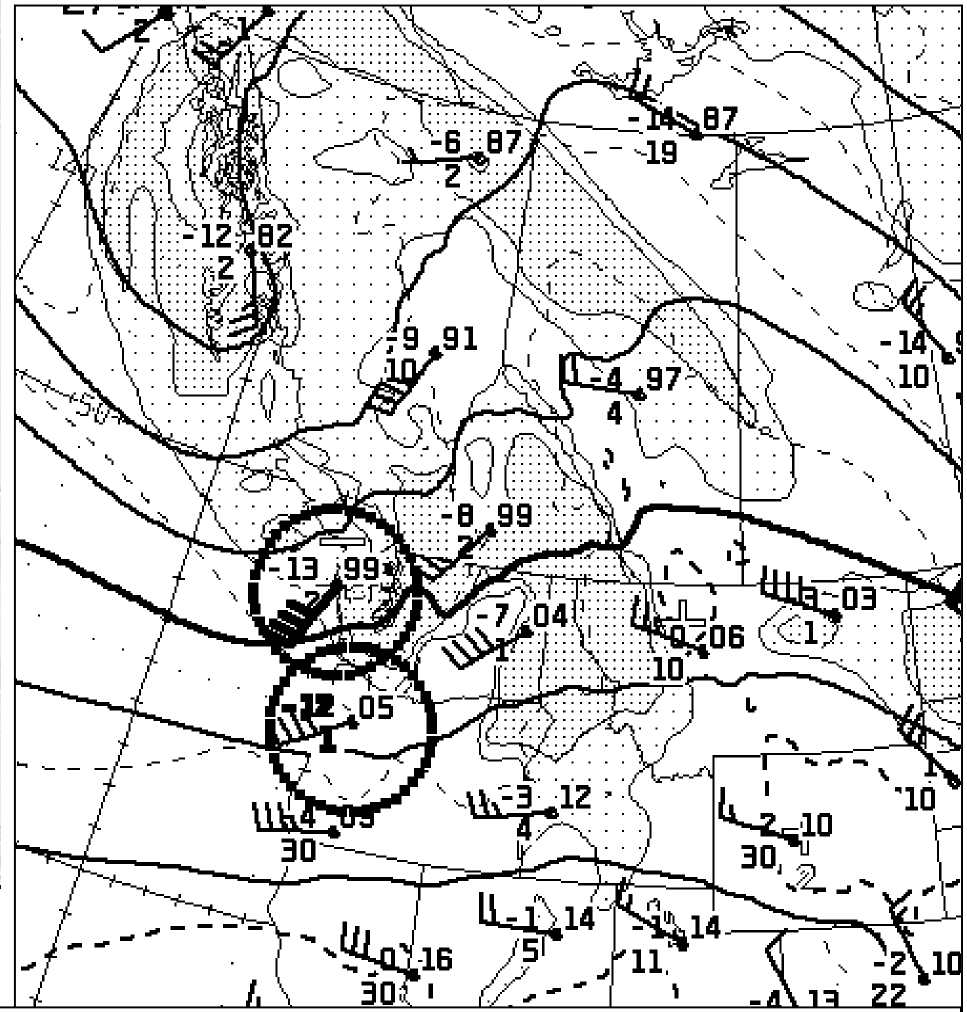
- high in the upper atmosphere, the low vapour pressure guarantees there can be little emission or absorption

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.

S. Alberta (Wikipedia) – looking towards the mountains

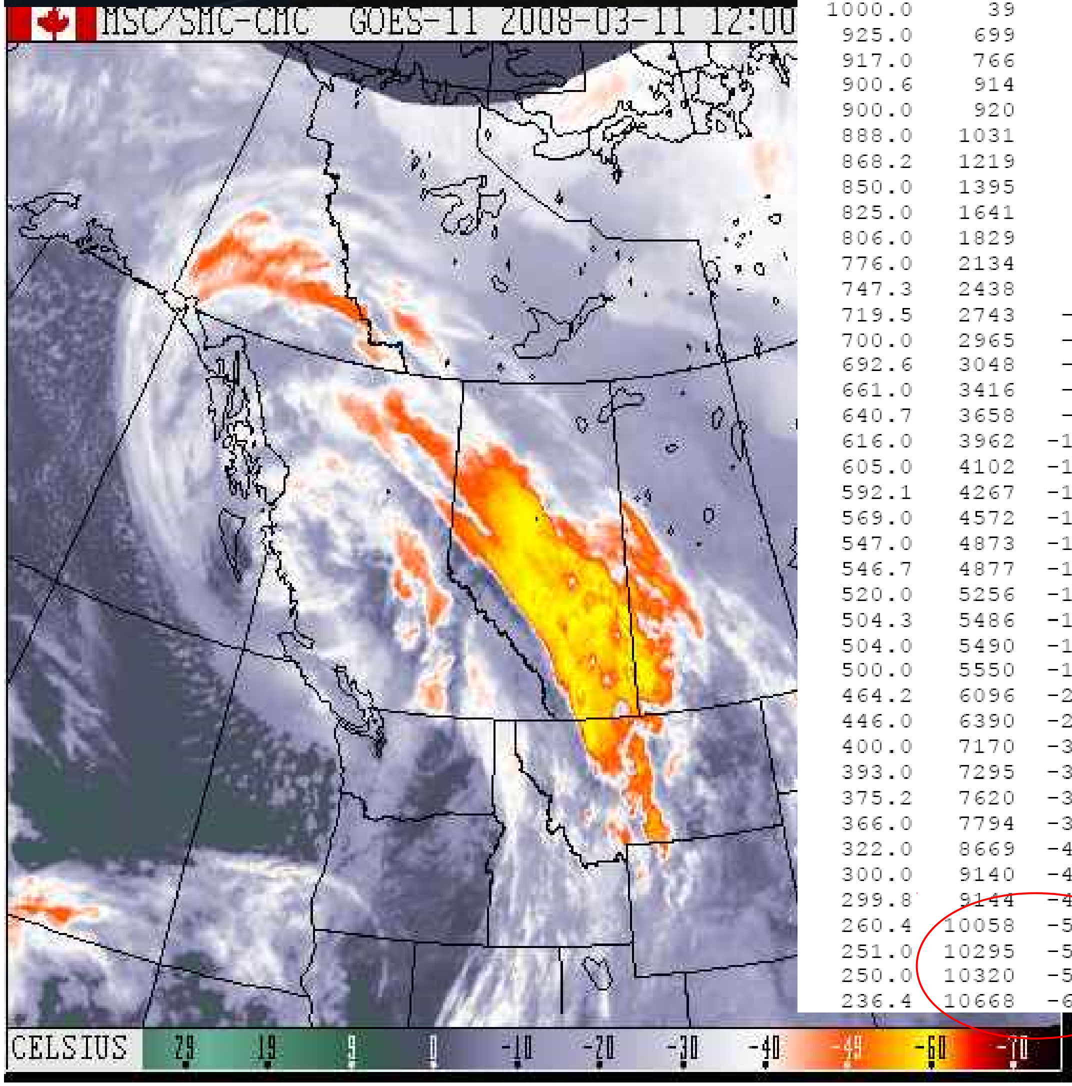


- dry slot in lee of Rockies – sinking air
- Chinook arch



700 hPa analysis 12 UTC 2008-03-11

Determine cloud top height over C. Alberta



2008

PRES hPa	HGHT m	TEMP C	DWPT C	RELH %	MIXR g/kg	DRCT deg	SKNT knot	THTA K	THTE K	THTV K
1000.0	39									
925.0	699									
917.0	766	1.8	-1.6	78	3.73	110	3	281.8	292.5	282.5
900.6	914	8.0	-1.8	50	3.74	130	12	289.6	300.7	290.3
900.0	920	8.2	-1.8	49	3.74	130	12	289.9	301.0	290.6
888.0	1031	9.4	-2.6	43	3.57	138	13	292.3	303.0	292.9
868.2	1219	8.7	-2.8	44	3.60	150	15	293.4	304.3	294.1
850.0	1395	8.0	-3.0	46	3.62	185	13	294.5	305.5	295.2
825.0	1641	7.2	-1.8	53	4.08	227	10	296.2	308.5	296.9
806.0	1829	5.7	-2.7	55	3.91	260	8	296.5	308.4	297.2
776.0	2134	3.1	-4.1	59	3.65	255	10	297.1	308.2	297.7
747.3	2438	0.6	-5.5	63	3.40	245	17	297.6	308.0	298.2
719.5	2743	-1.9	-7.0	68	3.17	250	19	298.0	307.8	298.6
700.0	2965	-3.7	-8.0	72	3.00	275	20	298.4	307.7	298.9
692.6	3048	-4.5	-8.3	75	2.98	280	21	298.4	307.6	298.9
661.0	3416	-7.9	-9.4	89	2.85	277	22	298.6	307.4	299.1
640.7	3658	-8.9	-10.4	89	2.71	275	23	300.1	308.6	300.6
616.0	3962	-10.1	-11.7	88	2.55	235	25	302.1	310.1	302.5
605.0	4102	-10.7	-12.3	88	2.47	237	25	303.0	310.9	303.4
592.1	4267	-11.6	-14.1	81	2.18	240	24	303.9	310.9	304.2
569.0	4572	-13.1	-17.4	70	1.72	260	25	305.5	311.1	305.8
547.0	4873	-14.7	-20.7	60	1.35	265	26	307.1	311.6	307.3
546.7	4877	-14.7	-20.7	60	1.35	265	26	307.1	311.6	307.3
520.0	5256	-17.3	-20.4	77	1.46	253	27	308.4	313.3	308.7
504.3	5486	-18.1	-22.6	68	1.25	245	27	310.2	314.4	310.4
504.0	5490	-18.1	-22.6	68	1.24	245	27	310.2	314.4	310.4
500.0	5550	-18.3	-22.9	67	1.22	250	26	310.7	314.8	310.9
464.2	6096	-22.5	-26.1	72	0.98	260	24	312.1	315.6	312.3
446.0	6390	-24.7	-27.9	75	0.87	256	26	312.9	316.0	313.1
400.0	7170	-30.9	-34.0	74	0.54	245	30	314.8	316.7	314.9
393.0	7295	-31.9	-35.0	74	0.50	242	31	315.0	316.9	315.1
375.2	7620	-34.2	-39.2	61	0.34	235	33	316.1	317.4	316.2
366.0	7794	-35.5	-41.5	54	0.28	236	33	316.7	317.8	316.8
322.0	8669	-43.5	-47.5	64	0.16	238	35	317.4	318.1	317.5
300.0	9140	-47.7	-52.4	58	0.10	240	36	318.0	318.4	318.0
299.8	9144	-47.7	-52.4	58	0.10	235	36	318.0	318.4	318.0
260.4	10058	-56.3	-60.5	59	0.04	235	37	318.6	318.7	318.6
251.0	10295	-58.5	-62.6	59	0.03	235	40	318.6	318.8	318.6
250.0	10320	-58.7	-62.8	59	0.03	235	40	318.7	318.8	318.7
236.4	10668	-60.8	-65.2	56	0.03	230	50	320.7	320.8	320.7

- dry slot in lee of Rockies
- Chinook arch
- cloud top over Edmonton -60°C, corresponds to 10 km above sea-level

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

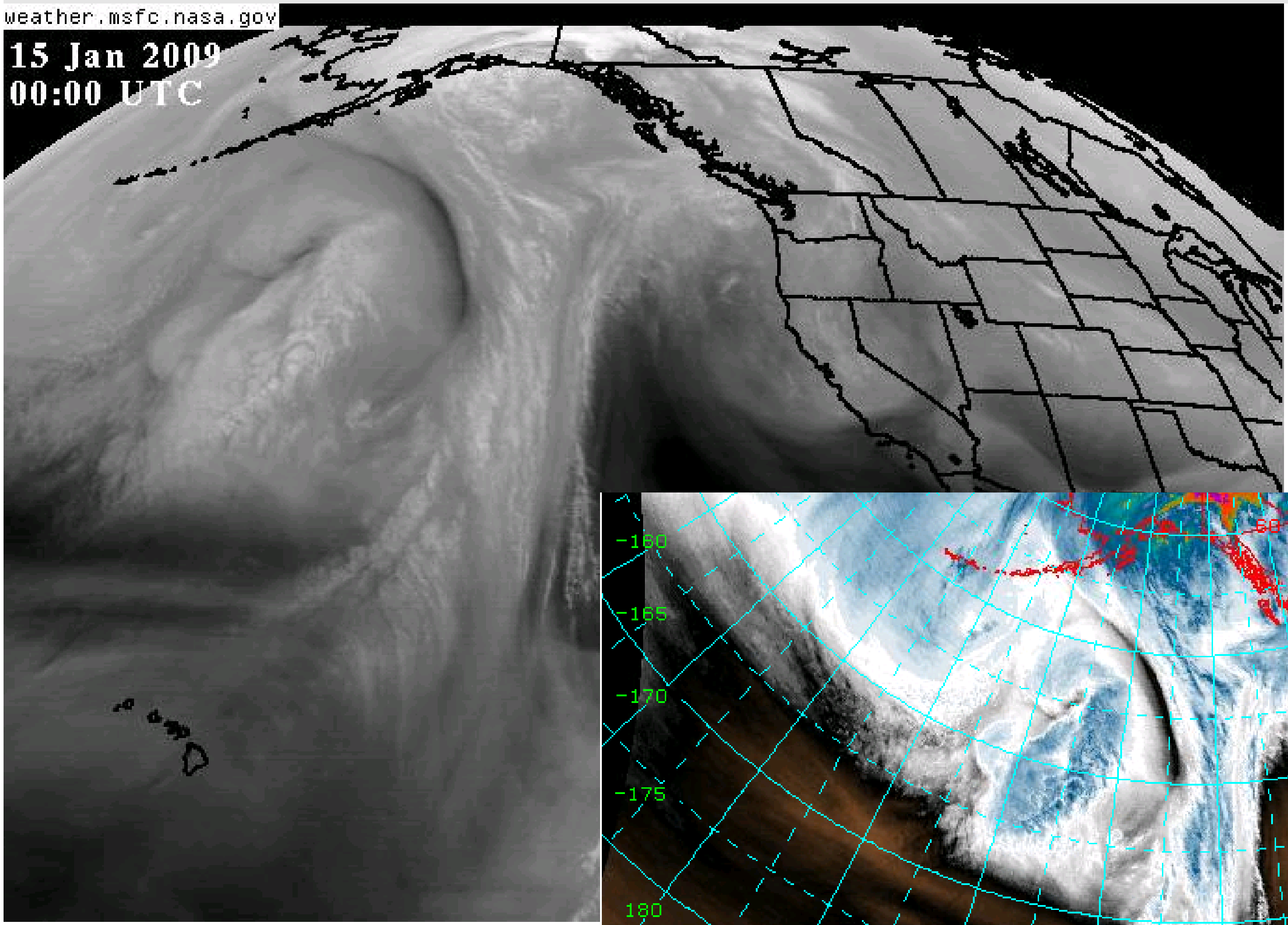
Cumuliform clouds

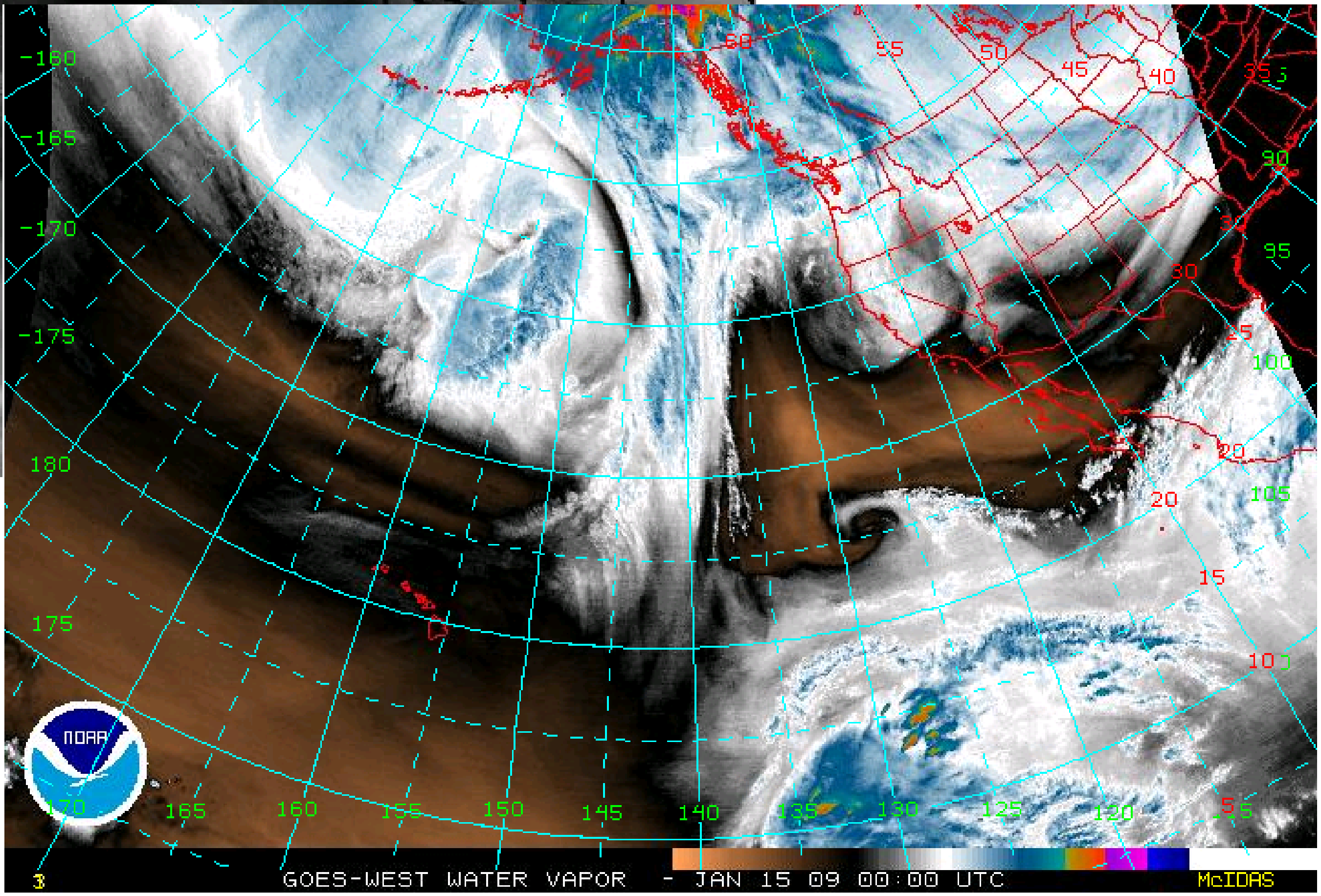
- stratocumulus: often arranged in sheets, lines or streets, esp. over water in winter; as a low cloud they will be dull/dark on the ir photo, but if thick enough bright and lumpy on the vis
- towering Cu or Cumulonimbus: bright on vis and ir; lumpy/shadowed on the vis

High level (cirro) clouds

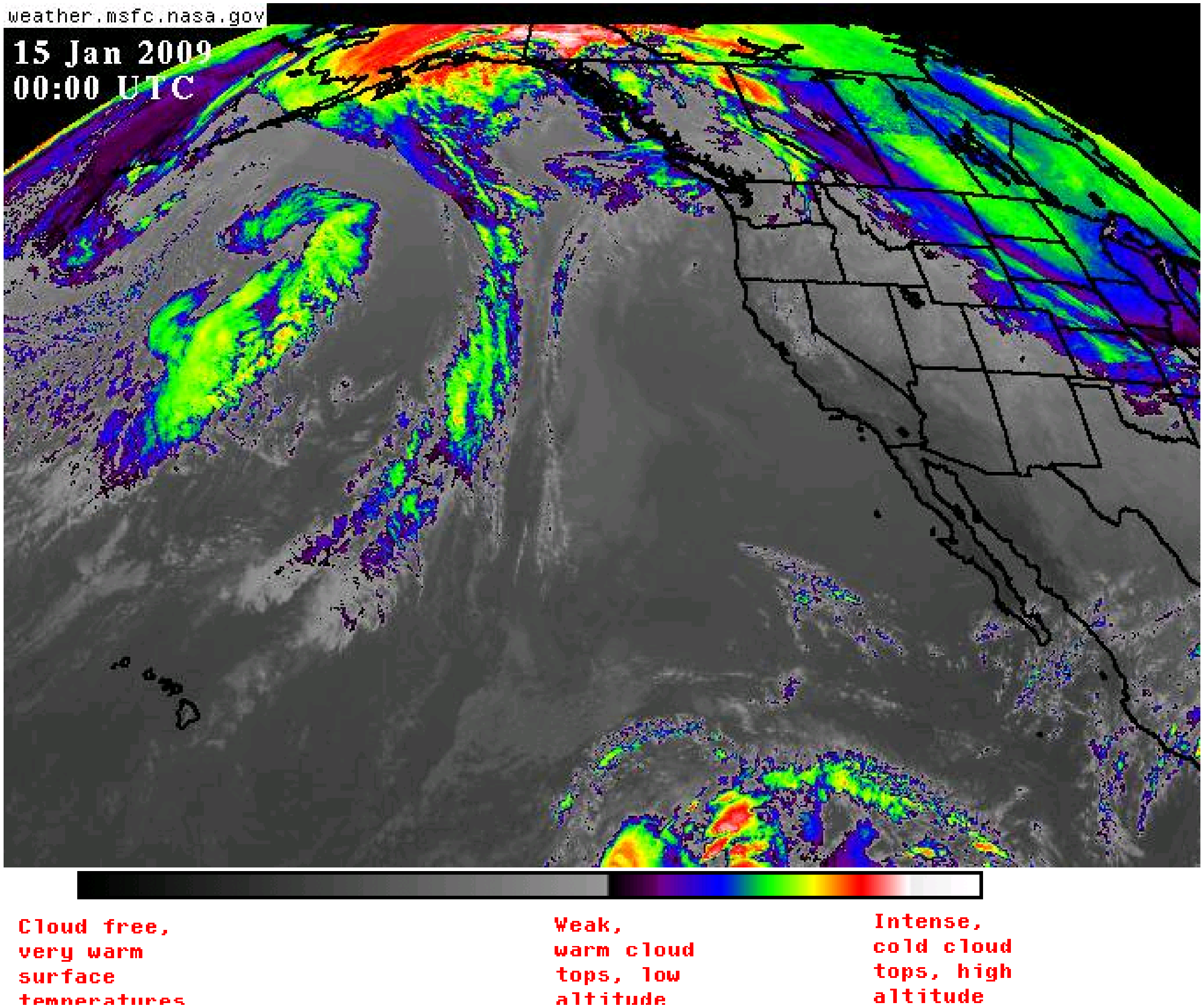
- being high, thick cirrus clouds will show high & cold (bright red/yellow) on the ir
- cirrus – fibrous appearance
- cirrocumulus – cellular
- cirrostratus – uniform

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

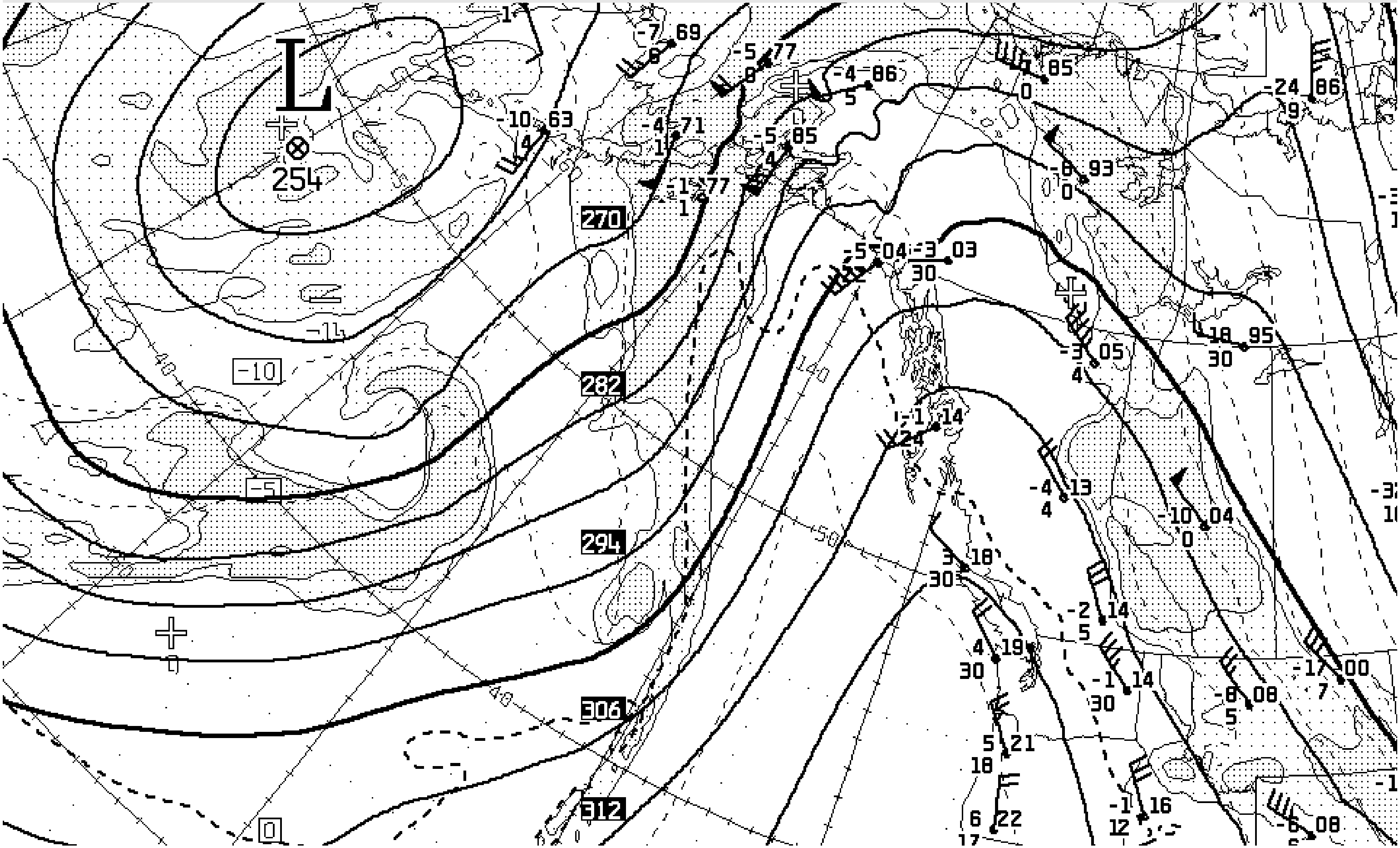




Compare initial state of CMC & NMC models with GOES west ir



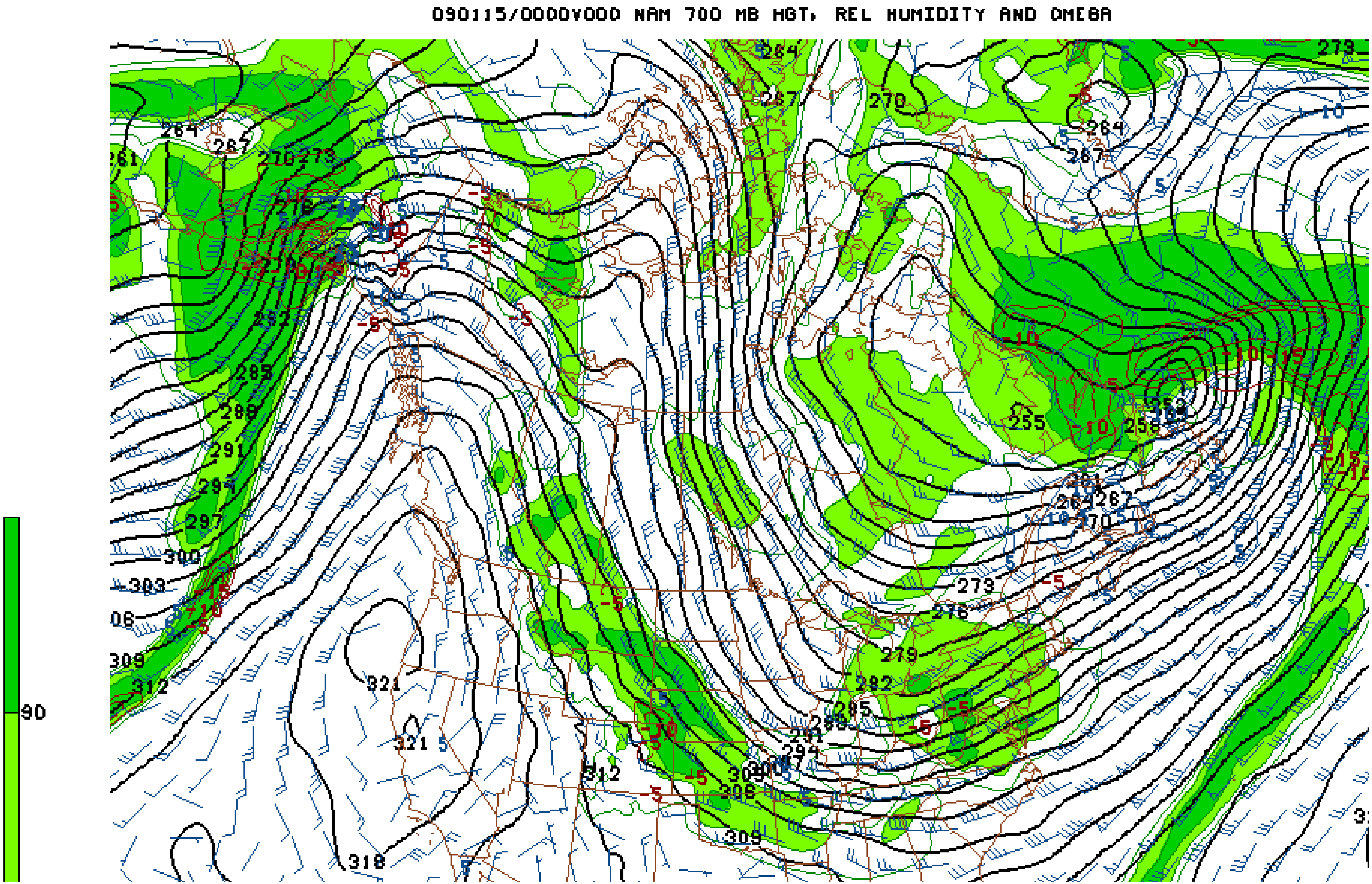
Compare initial state of CMC model with GOES west



Compare humidity features with the satellite images

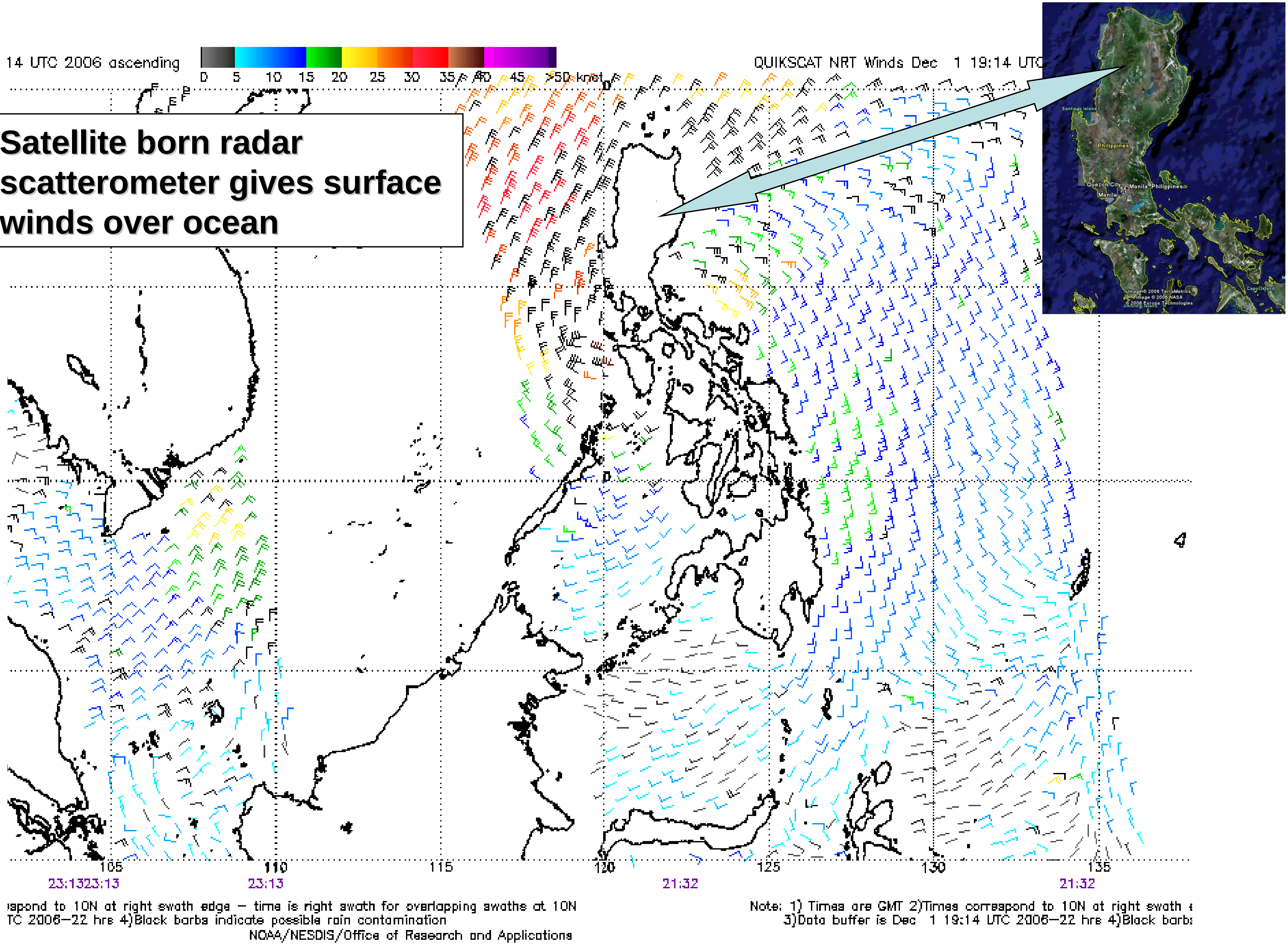
CMC 00h prog (i.e. analysis) valid 00 UTC Thurs 15 Jan. 2009

Compare initial state of NAM model with GOES west



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

Satellite born radar scatterometer gives surface winds over ocean



1 Dec. 2006 19:14 UTC

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