Goals for today:

•Ch 7, Precipitation Processes

19 Oct., 2011

"In this chapter we explain the processes by which nonprecipitating cloud droplets and ice crystals grow large enough to fall as precipitation"

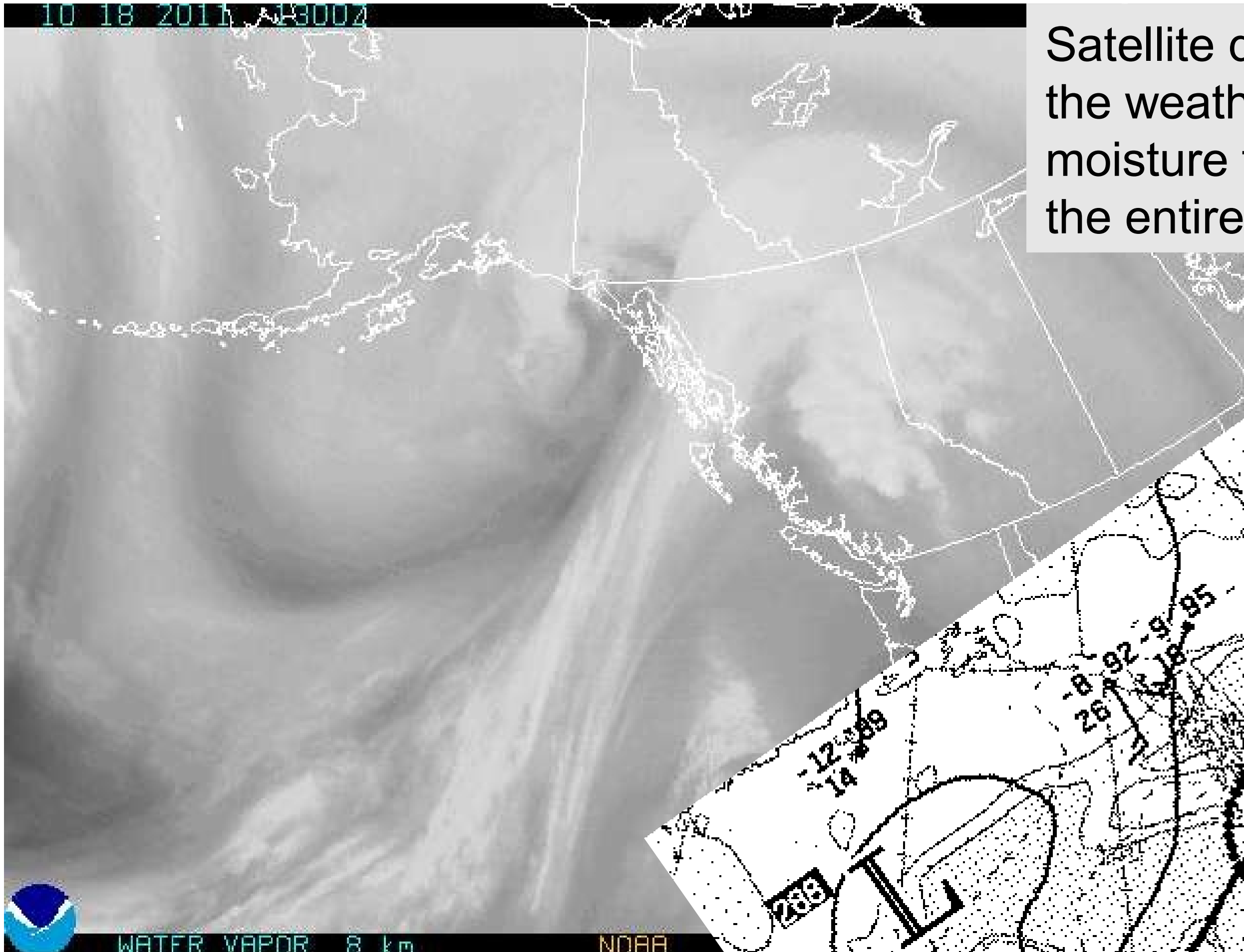
- Growth of Cloud Droplets
- Distribution and Forms of Precip

"within a few tens of metres of the lifting condensation level, all the available condensation nuclei have attracted moisture... (that) quickly attain diameters of about a micrometer" – too small to fall as precipitation – further growth entails competition for moisture

Cloud coverage is assessed qualitatively, following Table 6.3

Amount of Cloud Coverage	Condition
0	Clear
1/8 to 2/8	Few*
3/8 to 4/8	Scattered
5/8 to 7/8	Broken
8/8	Overcast

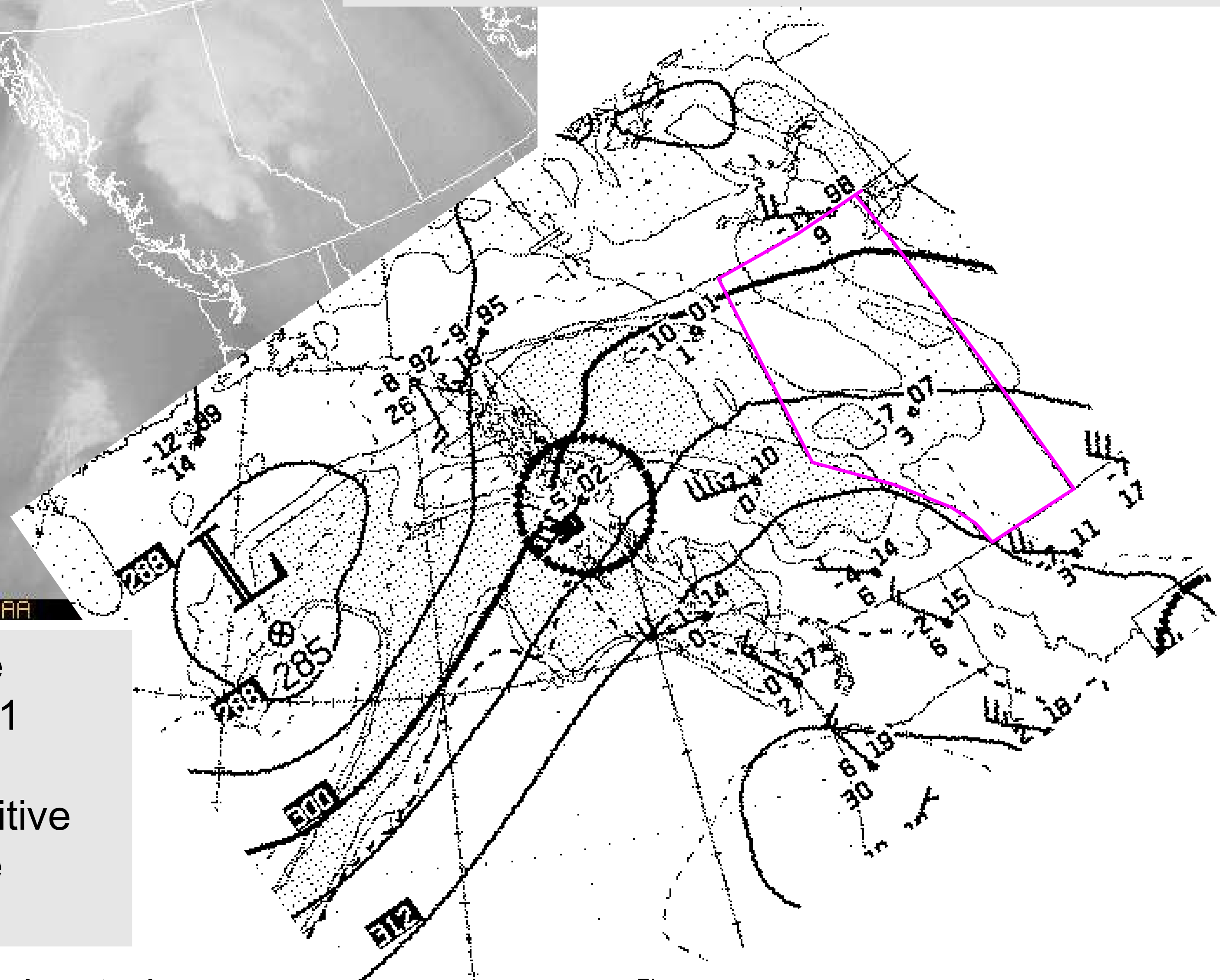
* *Any cloud coverage at all up to 2/8 is classified as "few."*



Satellite data are routinely used to initialize the weather forecast models, giving the moisture field at high spatial resolution over the entire globe ("data assimilation")

GOES geostationary satellite image 13Z Tues 18 Oct. 2011

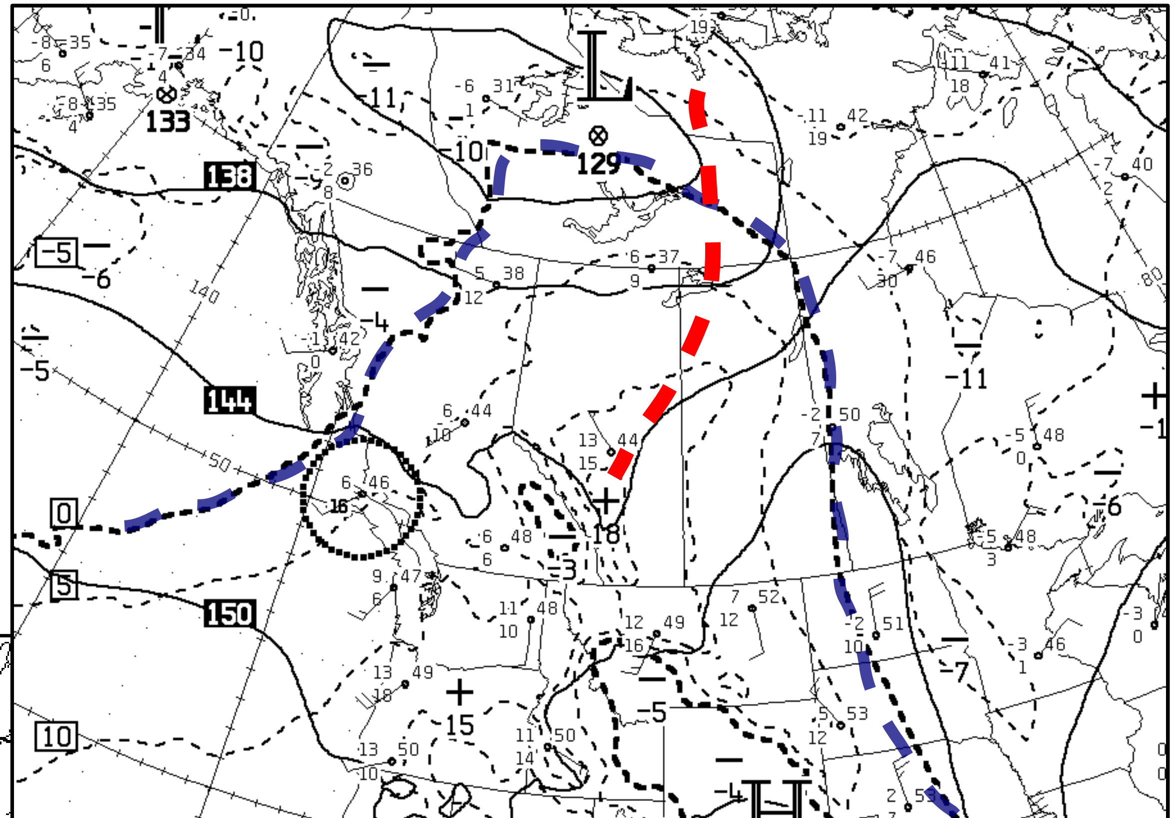
"Water Vapor Channel" sensitive to water vapour in the middle troposphere (c.f. Sec. 5-3)



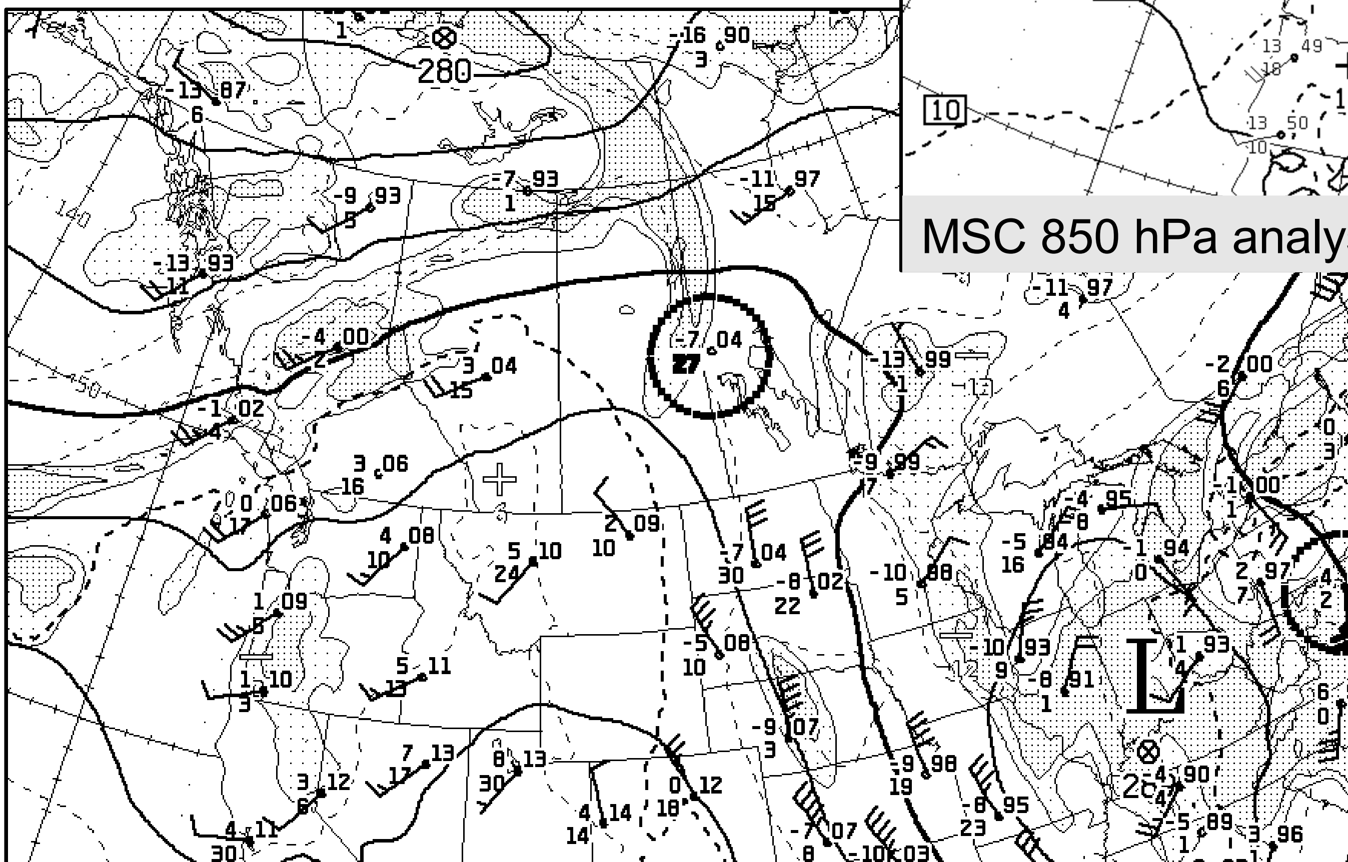
MSC 700 hPa analysis, 12Z Tues 18 Oct. 2011 (heavy stippling, $T\text{-}T_d \leq 2^{o}$C)

Moisture aloft is being advected around an upper low offshore and onto B.C. and Ab.

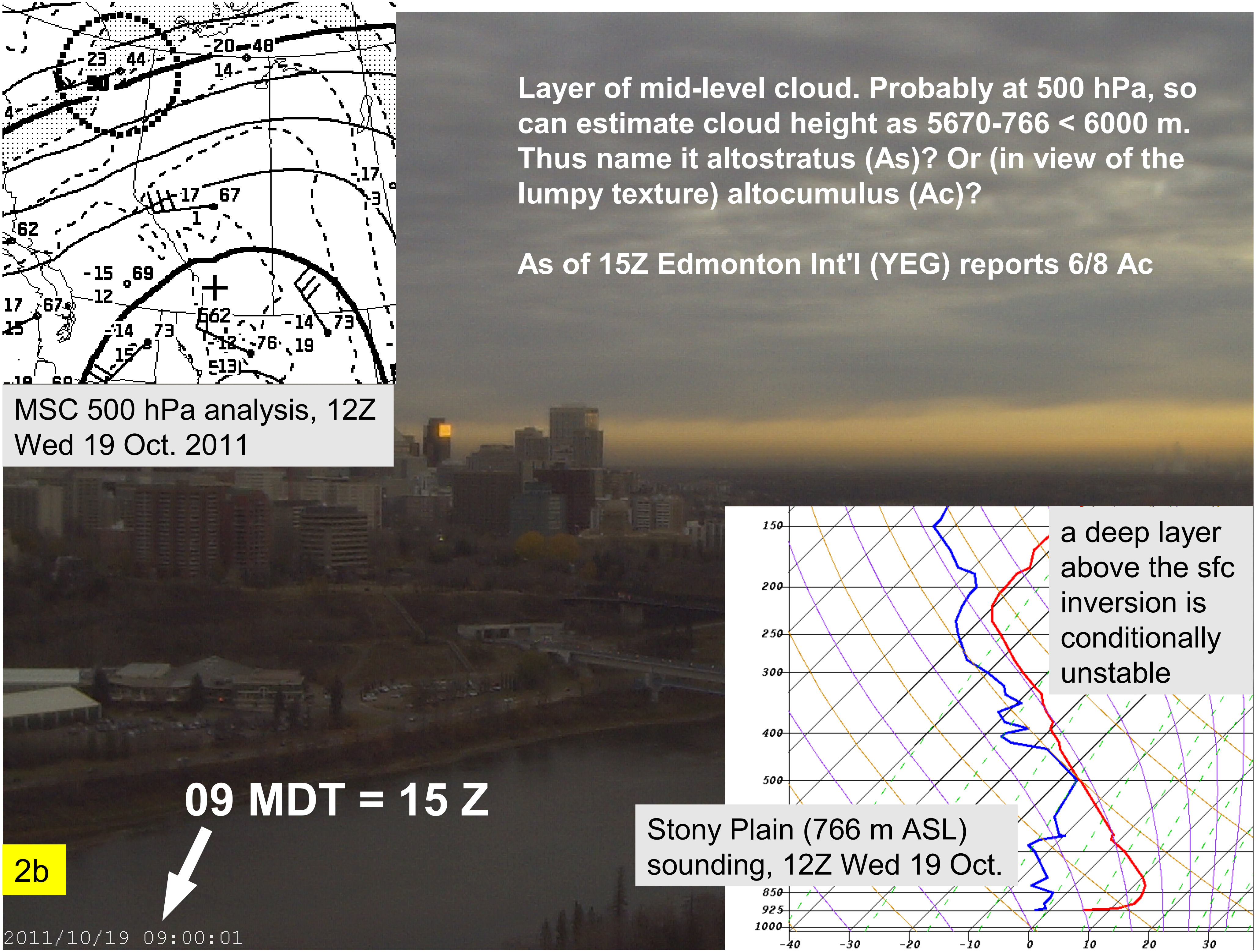
The westerly flow aloft has pushed mild air over western Canada. The closed upper low now over eastern U.S. has sucked cold air over the eastern continent. This pattern is highlighted by the freezing contour, whose shape identifies the thermal ridge (axis of higher temperature)



MSC 850 hPa analysis, 12Z Wed 19 Oct. 2011



2a MSC 700 hPa analysis, 12Z Wed 19 Oct. 2011


Layer of mid-level cloud. Probably at 500 hPa, so can estimate cloud height as 5670-766 < 6000 m. Thus name it altostratus (As)? Or (in view of the lumpy texture) altocumulus (Ac)?
As of 15Z Edmonton Int'l (YEG) reports 6/8 Ac
MSC 500 hPa analysis, 12Z Wed 19 Oct. 2011
09 MDT = 15 Z
2b
2011/10/19 09:00:01
a deep layer above the sfc inversion is conditionally unstable
Stony Plain (766 m ASL) sounding, 12Z Wed 19 Oct.
150
200
250
300
400
500
850
925
1000
-40
-30
-20
-10
0
10
20
30

“Condensation can lead to rapid droplet growth, but only until they achieve radii up to about 20 μm” (p204)

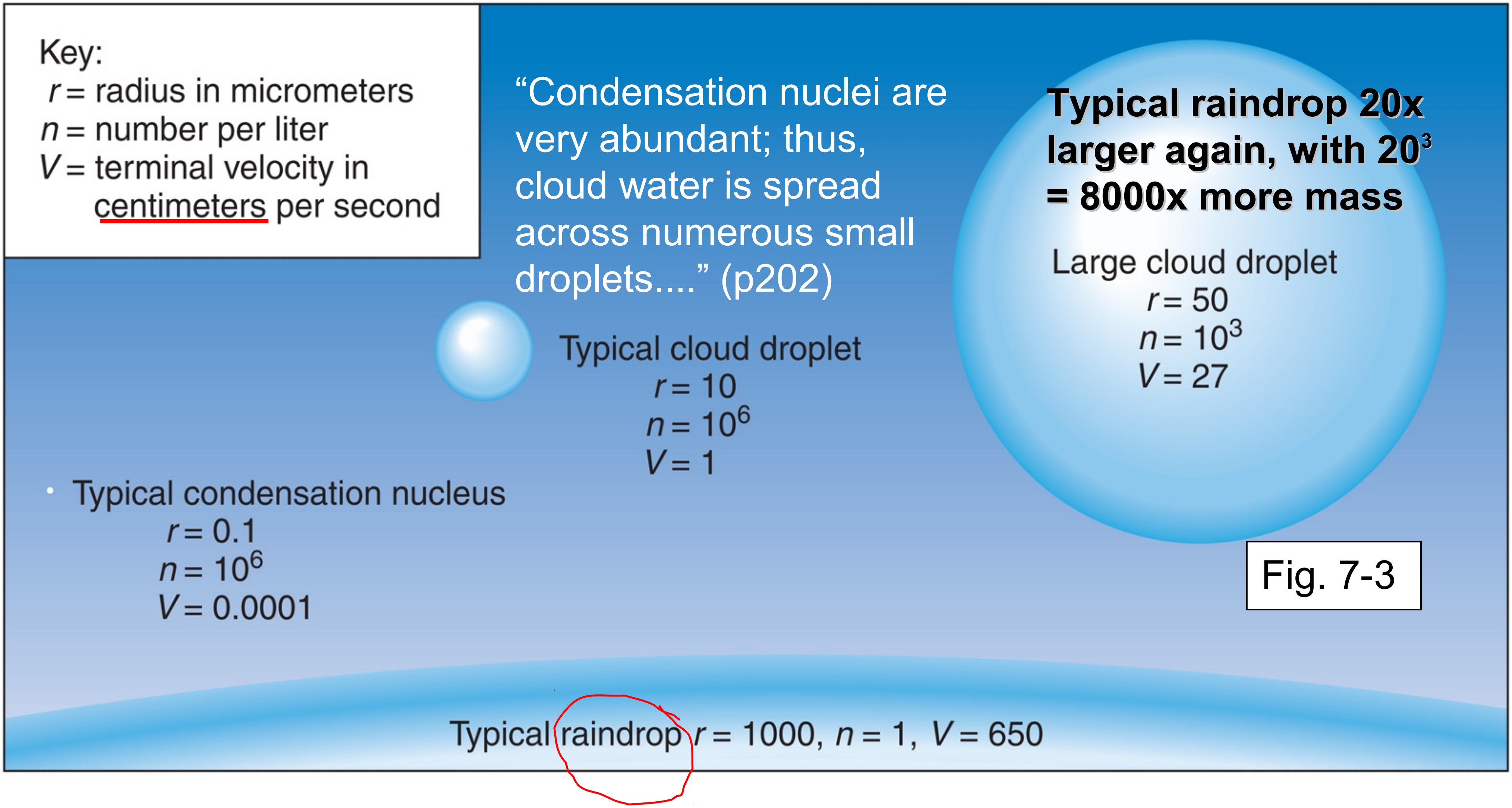
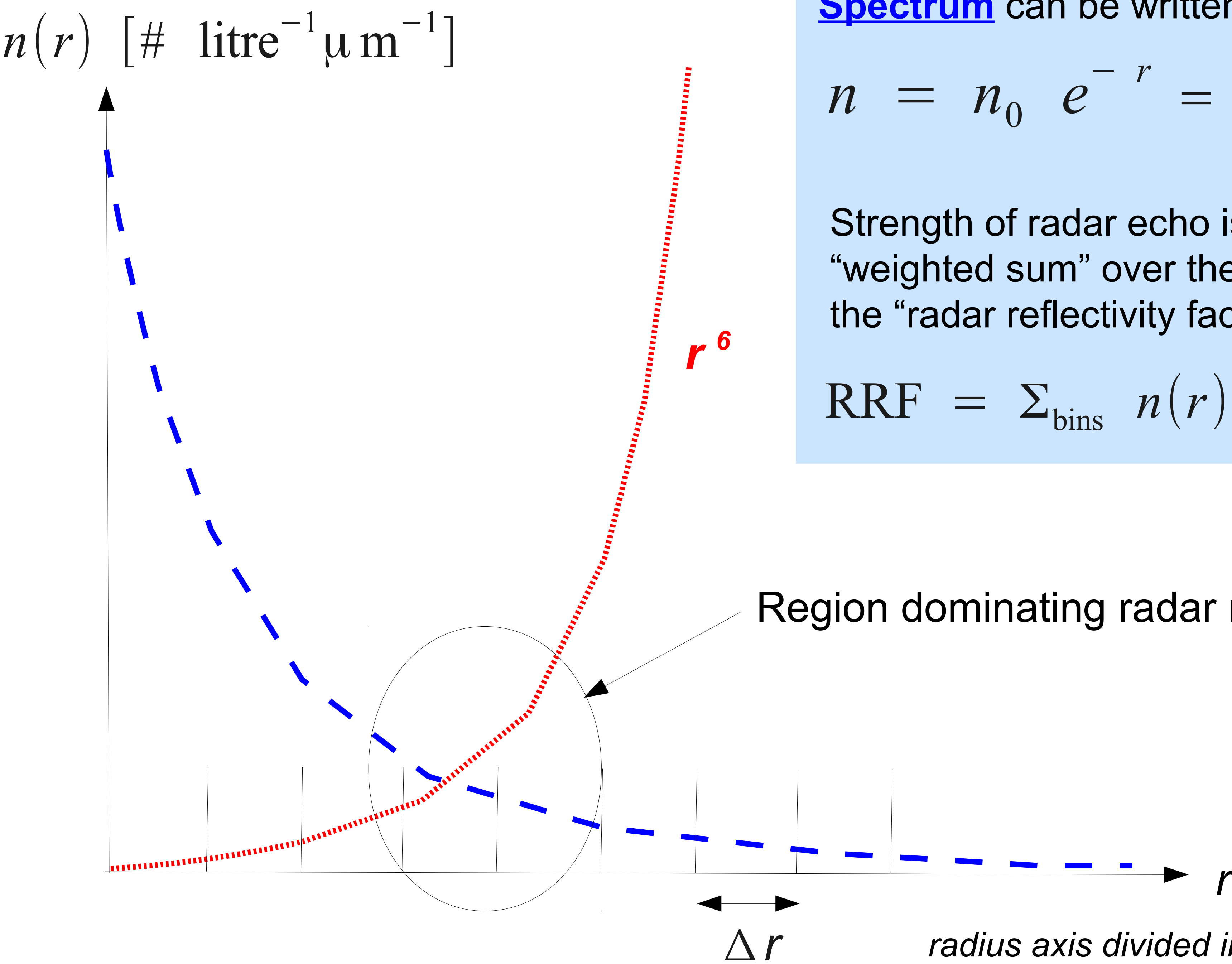


Fig. 7-3

Cloud droplet size spectrum and radar response



Spectrum can be written:

$$n = n_0 \, e^{-r} = \frac{n_0}{2.7183^r}$$

Strength of radar echo is a "weighted sum" over the spectrum: the "radar reflectivity factor" is

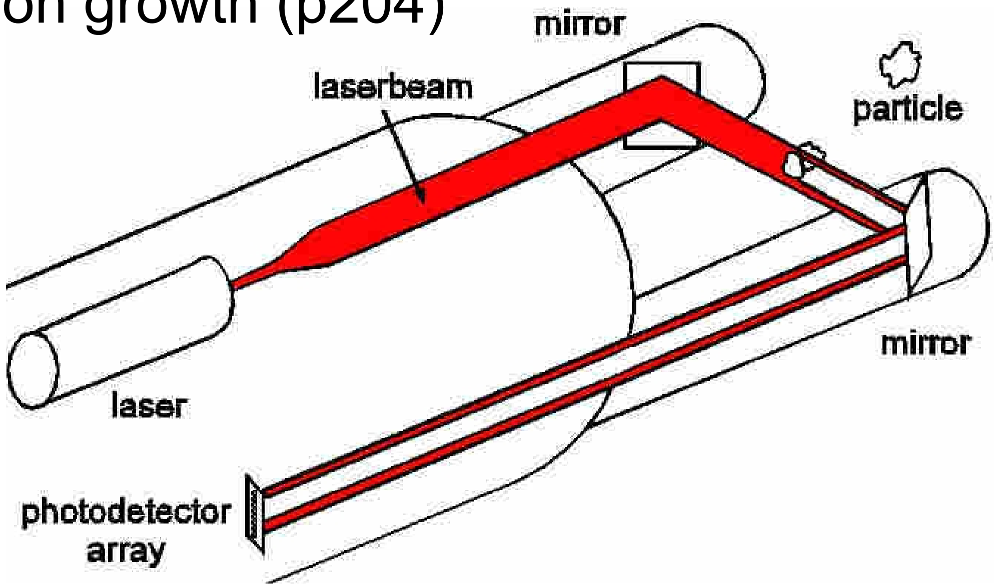
$$\mathrm{RRF} = \Sigma_{\mathrm{bins}} \; n(r) \; r^6 \; \Delta r$$

Water vapour + lifting parcel → CLOUD

Liquid water at the base of a cloud initially forms onto condensation nuclei ("CCN"), of which there are a very large number.

"Within a few tens of meters of the LCL all the available condensation nuclei have attracted moisture… they quickly attain diameters of about a micrometer" (p191; p204)

These are in competition for water vapour… "cloud water is spread across numerous small droplets rather than being concentrated in fewer large drops" (p202) and "with so many droplets competing, none can grow very large" by condensation growth (p204)



CLOUD → PRECIPITATION?

- **How do some cloud droplets grow large enough to fall as precip?**

Terminal velocity V of spherical droplets (correcting errors in Sec 7-1)

Gravitational force (directed down, so let's give it a negative sign):

$$F_g = -\rho_w \frac{4}{3} \pi r^3 g$$

volume

Drag of air on particle (directed upwards, against the direction of slip):

$$F_d = k\,(4 \pi r^2)\,\rho V^2$$

area

ρ is air density. Easy to show circled term has units of pressure, i.e. N m^{-2} = Pa

k is the "drag coefficient" (dimensionless). Units of F_d are [m^2 Pa = N]

Terminal velocity V of spherical droplets (applies also to hailstones)

Sum of the two forces is the acceleration, which is zero once the particle has attained its “terminal” velocity:

$$\frac{\Delta V}{\Delta t} = 0 = F_d - F_g$$

(particle acceleration = 0)

Rearrange to isolate *V* :

$$V\ [\mathrm{m\,s^{-1}}] = \sqrt{\frac{\rho_w\ g}{3\ \rho\ k}}\ \sqrt{r}$$

Coefficient evaluates to about 20 for hail (with *r* in cm)

Check: does this formula make sense from point of view of units? Does it give values compatible with Table 7-1?

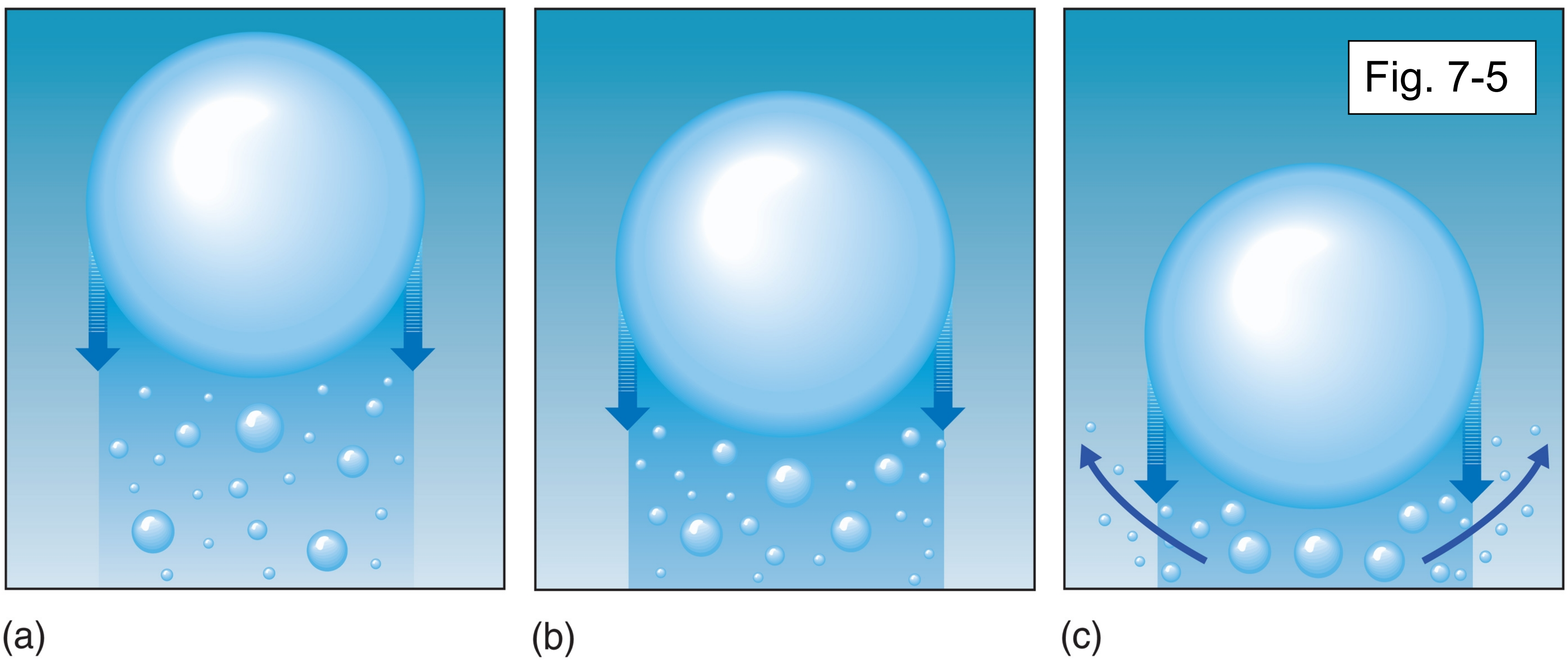
Hailstone kinetic energy $\frac{1}{2} m V^2 \propto r^4$

“a small droplet is easily suspended”

Growth in Warm Clouds: collision-coalescence process

• larger drops with greater terminal velocity assimilate smaller

• collision efficiency low for droplets of size nearly equal to that of the "collector" droplet, and for droplets very much smaller than collector



Growth in Cool and Cold Clouds: Bergeron process

- depends on co-existence of mixture of ice and liquid water

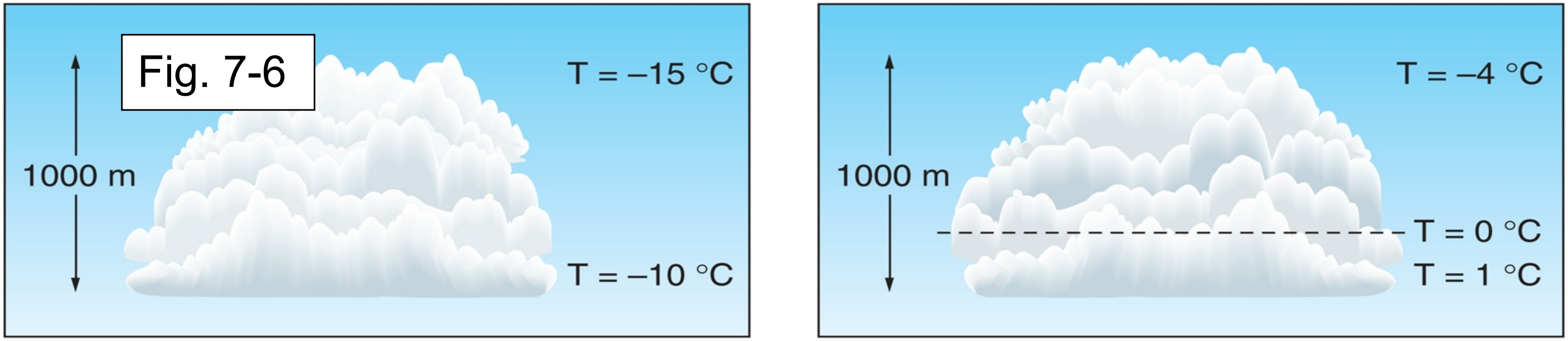


Fig. 7-6
(a) (b)

T[°C]	$e_s(T)$, hPa (Ice)	$e_s(T)$, hPa (Water)
-1	562	568
-2	517	528

- **Equilib. vapour pressure over ice is less than over supercooled water at same temp: (H_2O molecules bound in a crystal lattice require more energy to "escape")***

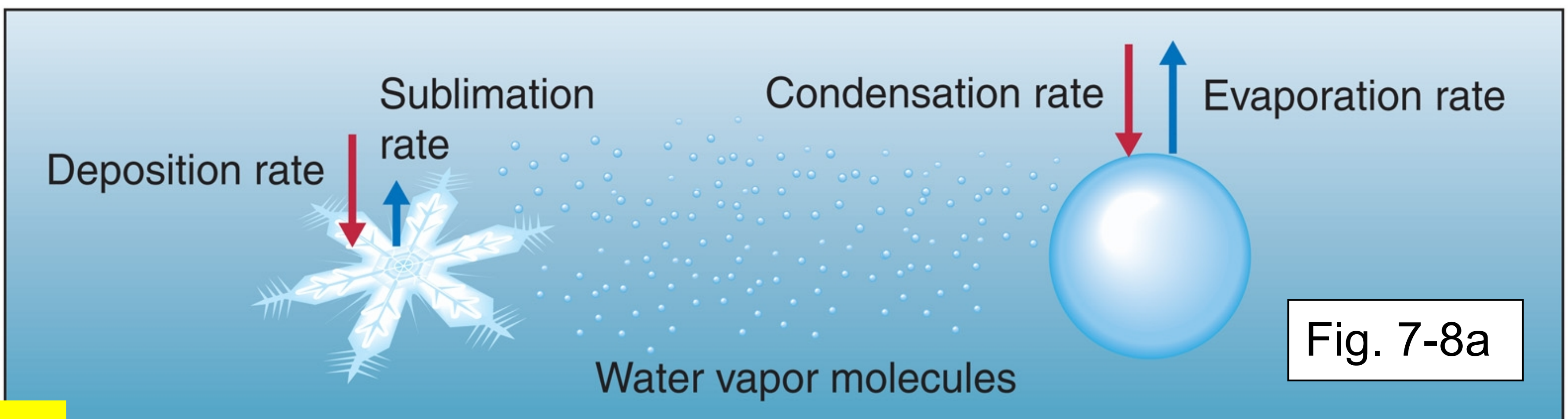


Fig. 7-8a

***This was discovered by Alfred Wegener, who also is credited with the theory of continental drift**

(See tutorial on CD)

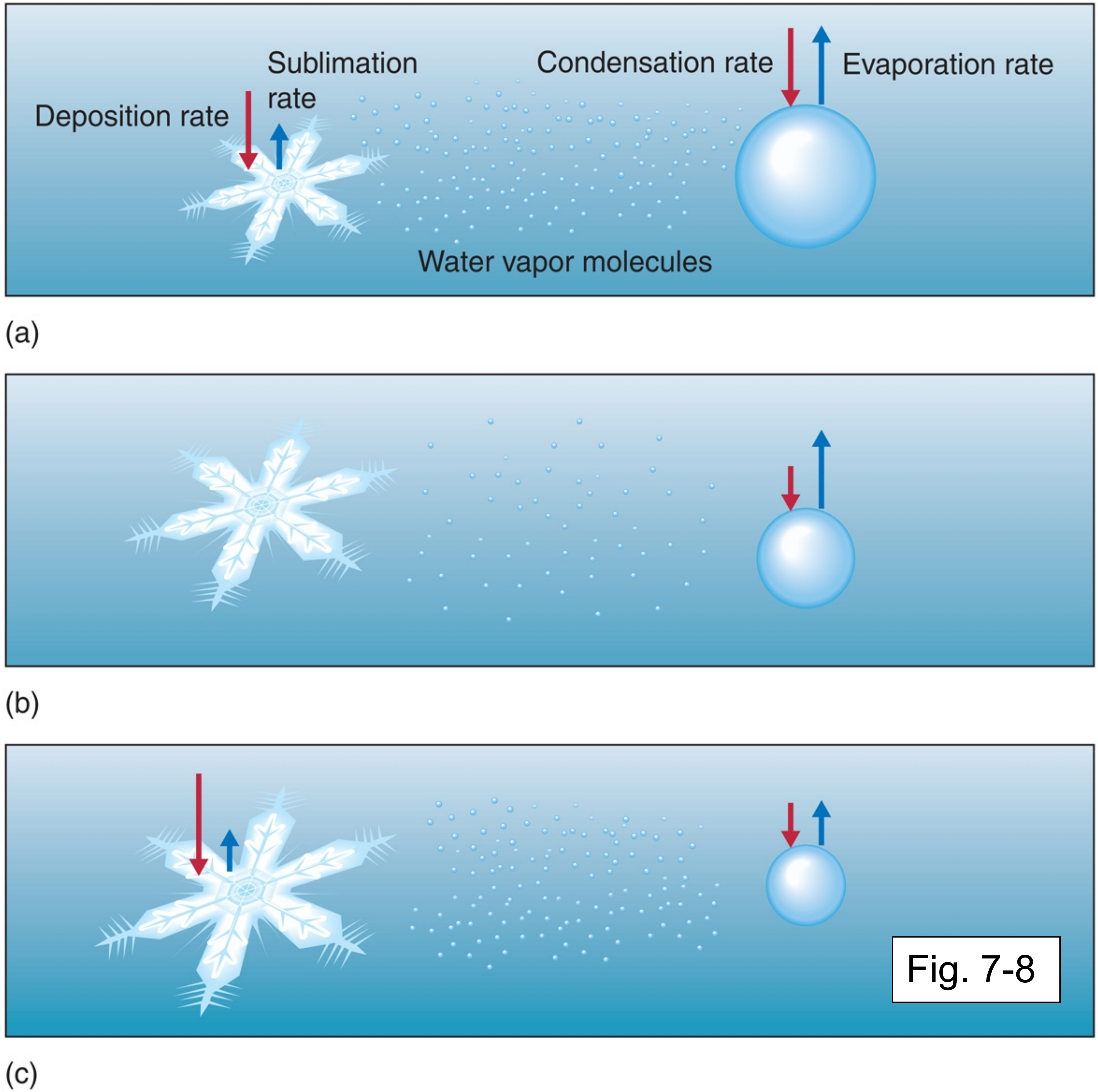
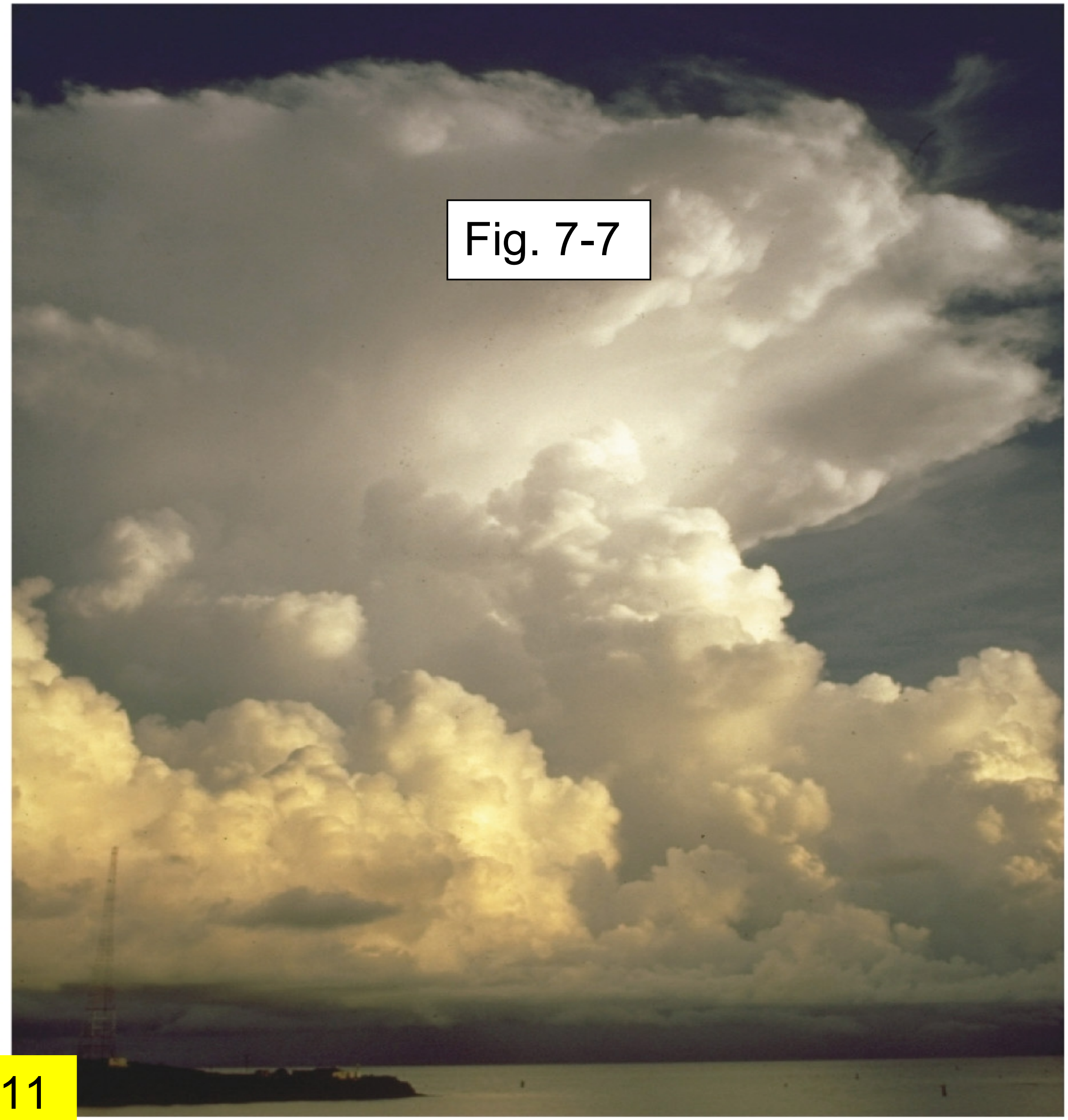


Fig. 7-8

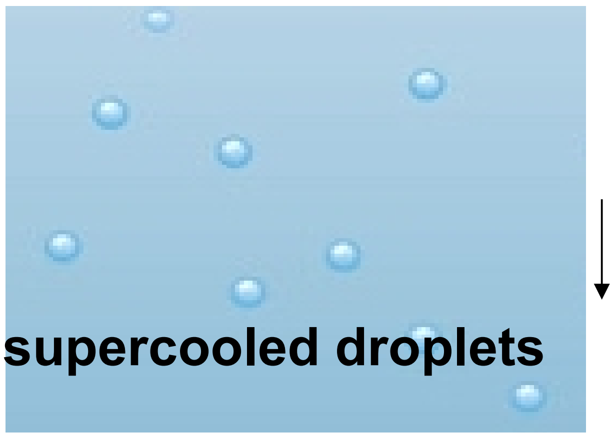
Growth in cold clouds, e.g. cumulonimbus
liquid (bottom, sharp margins) and mix of ice and liquid (middle)

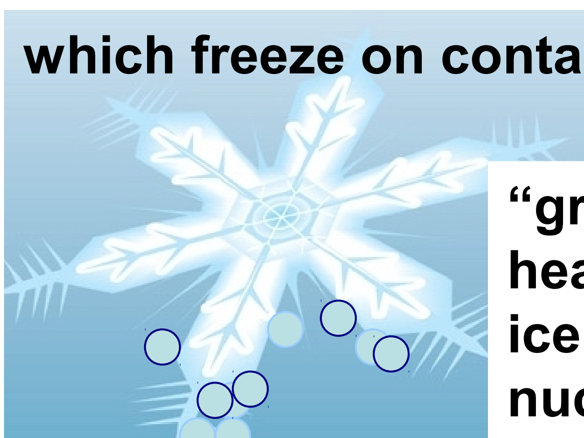


Upper region, ice particles (fuzzy cloud margins)

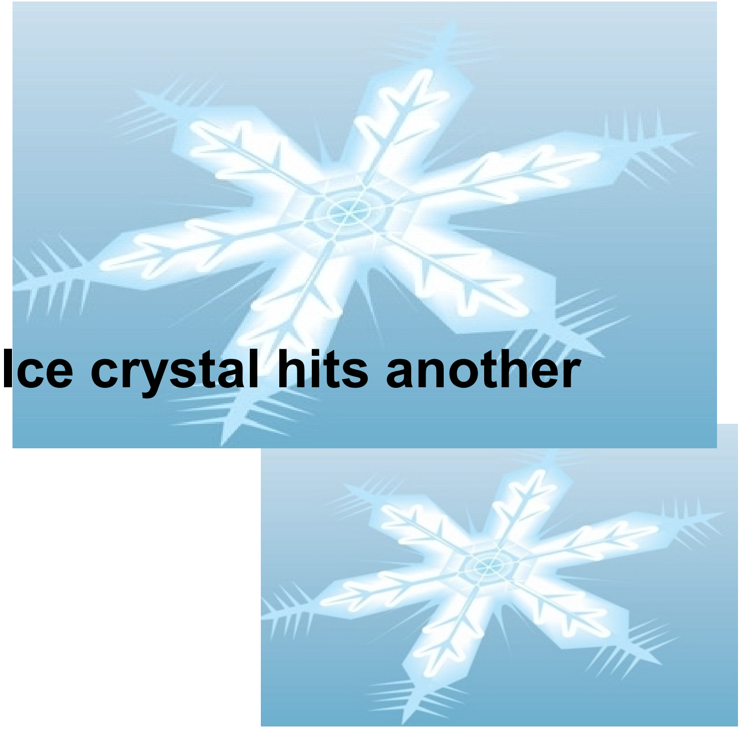
Lower region, liquid (sharp margins)

Riming (accretion) and Aggregation





"graupel" - heavily rimed ice crystal - nucleus of hailstone



Aggregation is easier if there is a film of water on the ice: bigger flakes from warmer clouds

"What happens to these crystals as they fall determines the type of precipitation that occurs"

• "ice crystal takes on additional mass by riming, its original six-sided structure becomes obscured"

• air bubbles may be enclosed ("spongy ice")

Snow:

• ice crystals in clouds can have wide variety of shapes (dendrites, plates, columns)

• infinite variety of snowflack forms (even multiple forms within one flake) because each regime of T, T_d will favour a different structure

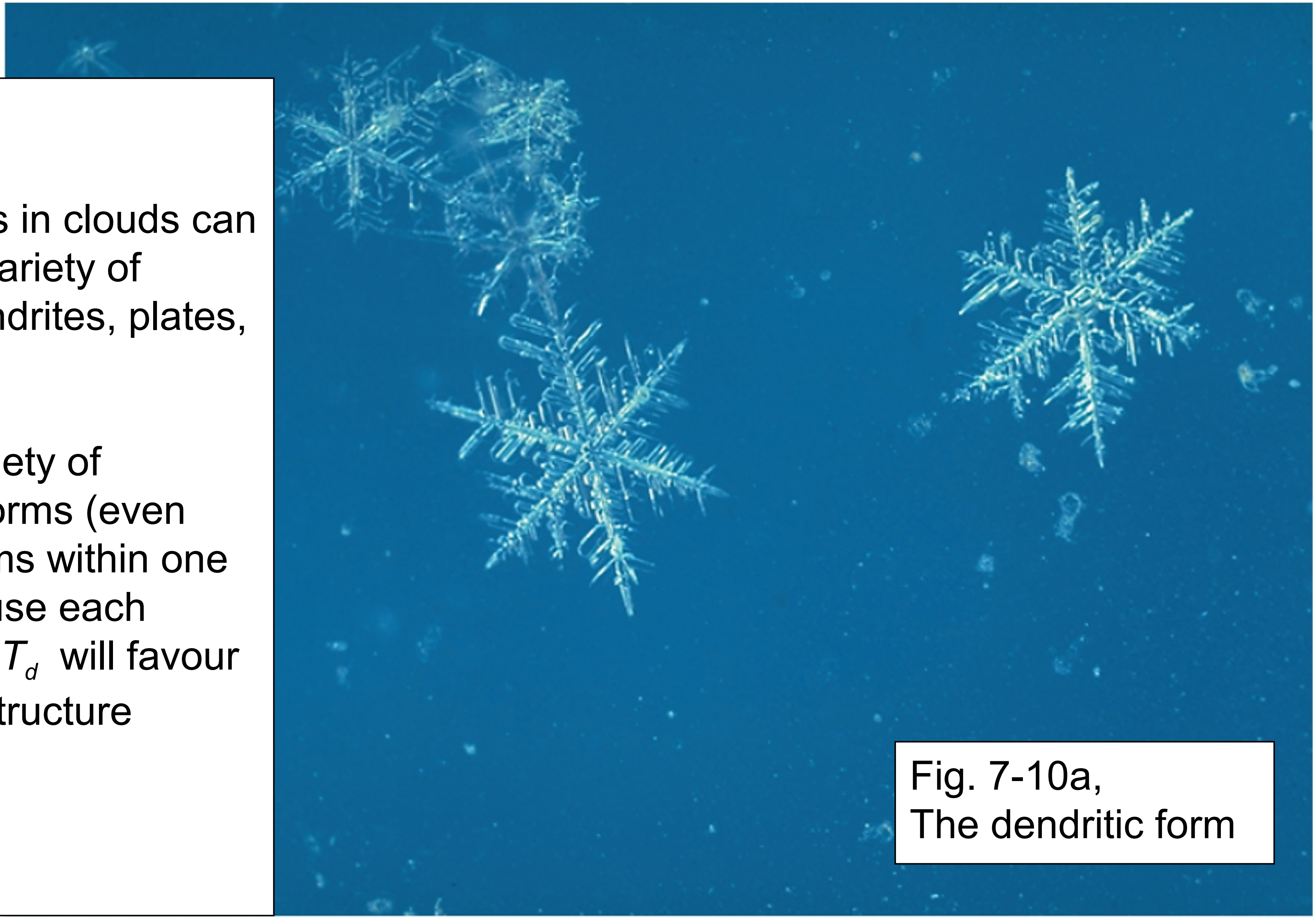
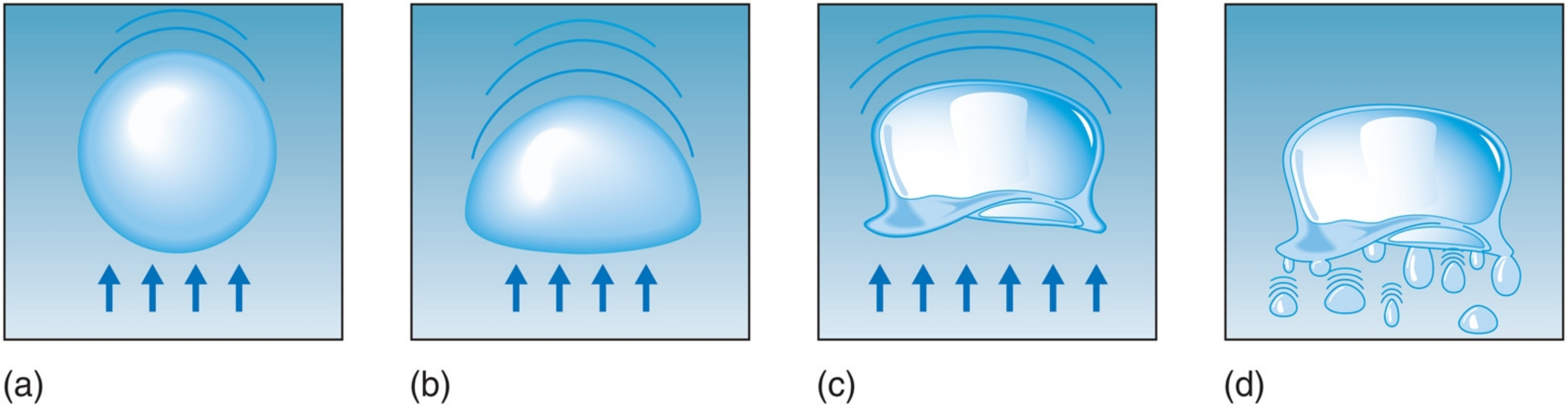


Fig. 7-10a,
The dendritic form

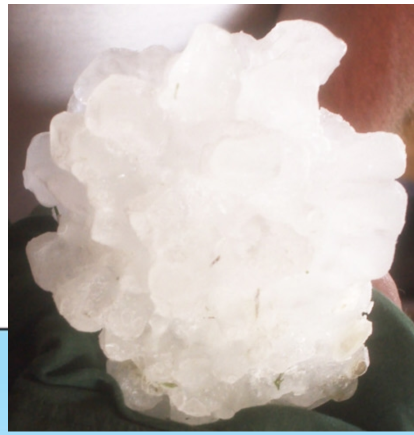
- first drops tend to be large – because due to their larger size they fall fastest. Their partial evaporation humidifies the air column so that the smaller drops, initially greatly diminished by evaporation, survive to the ground

- due to droplet breakup, raindrop diameter seldom exceeds 5 mm

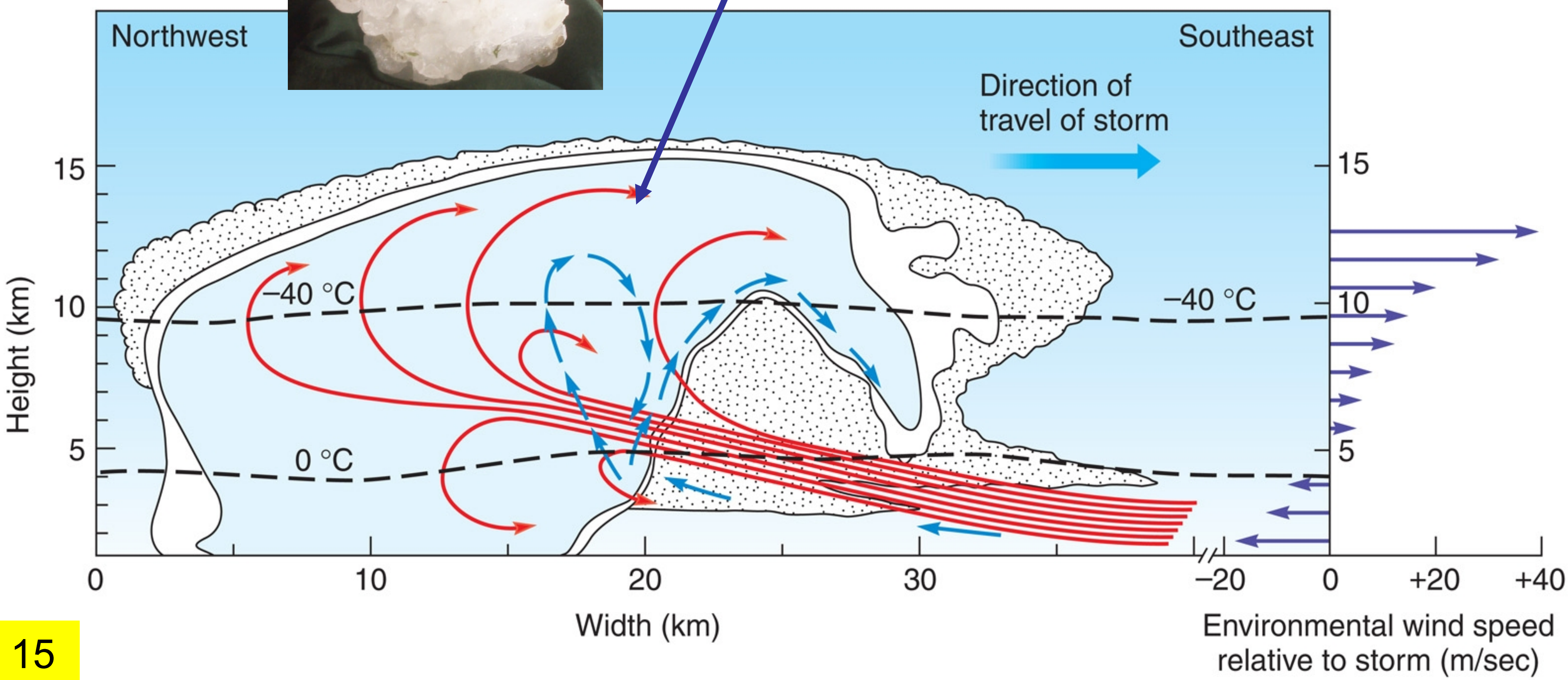


Graupel & Hail:

graupel – heavily rimed ice crystals, diameter up to about 5 mm, may fall to ground or if they remain suspended, form nuclei of hailstones

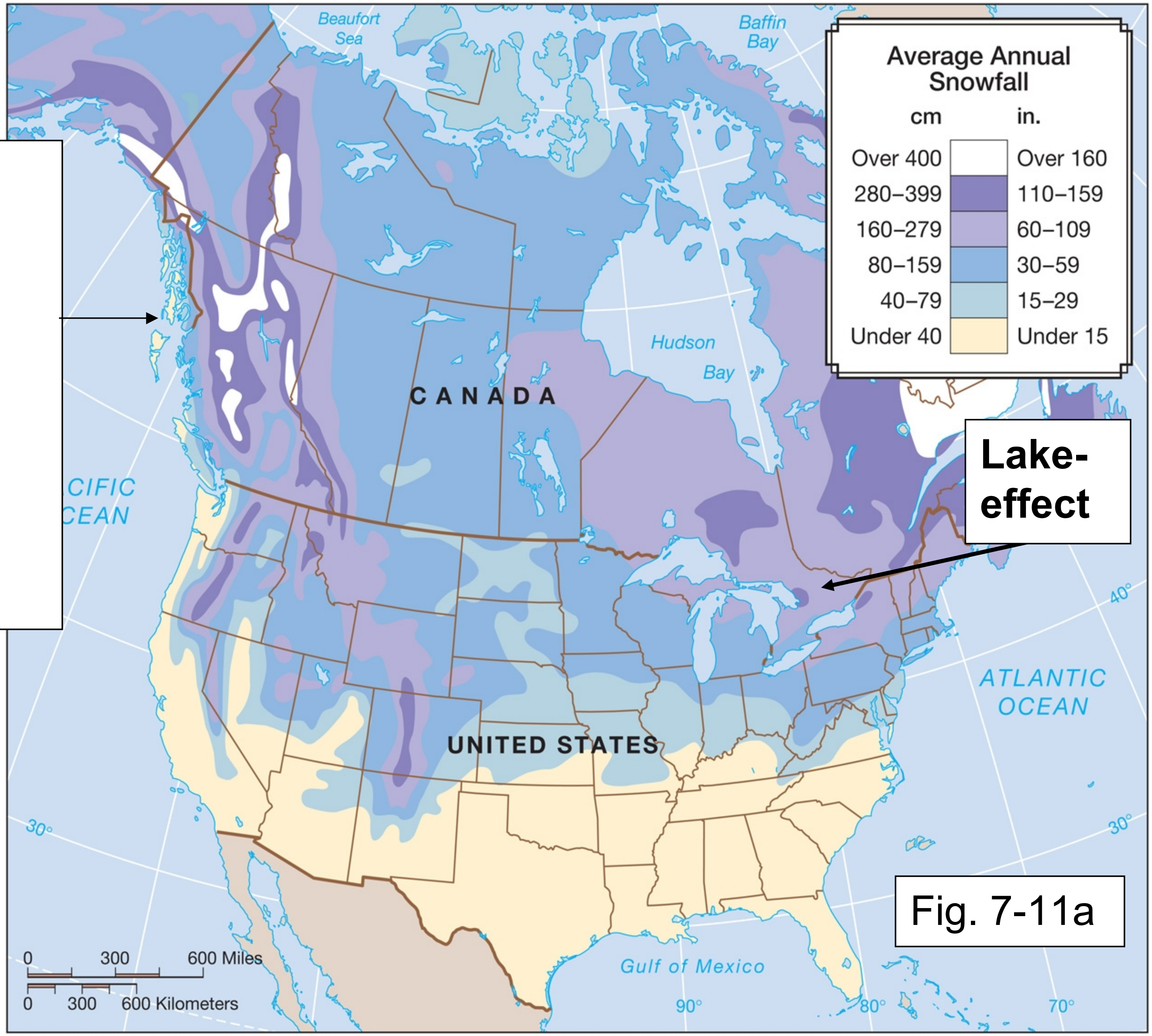


Successive passages above/below freezing level result in layered hailstone; not much air due to the melting stages



Distribution & Forms of Precip

- **westerlies dominant**
- **advect moisture onshore**
- **upslope through B.C.**

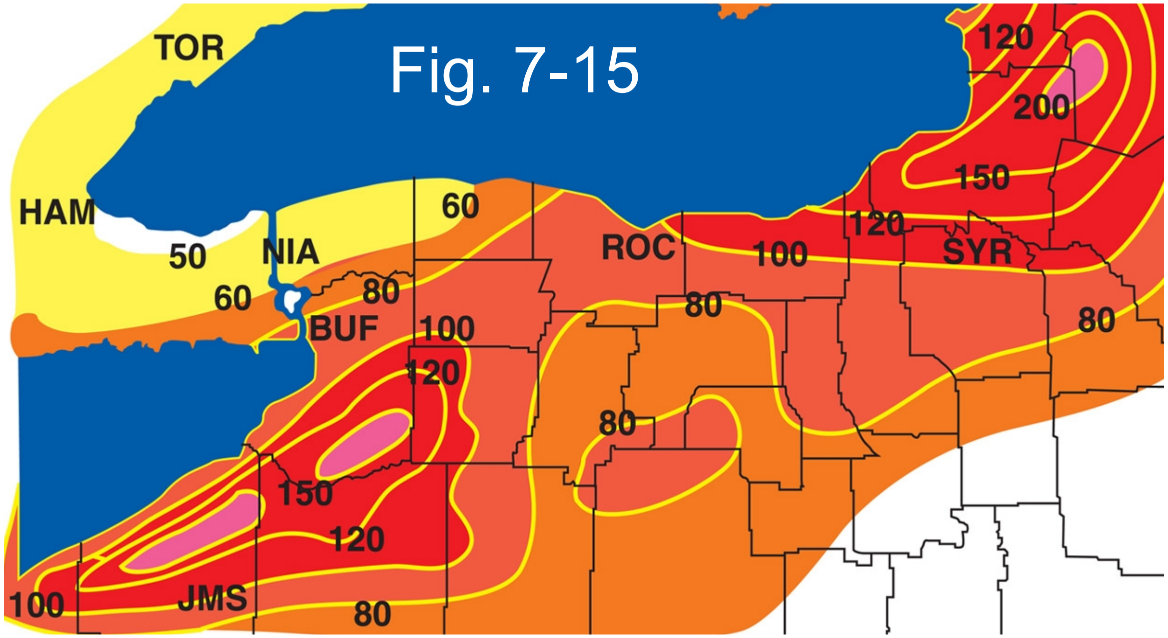


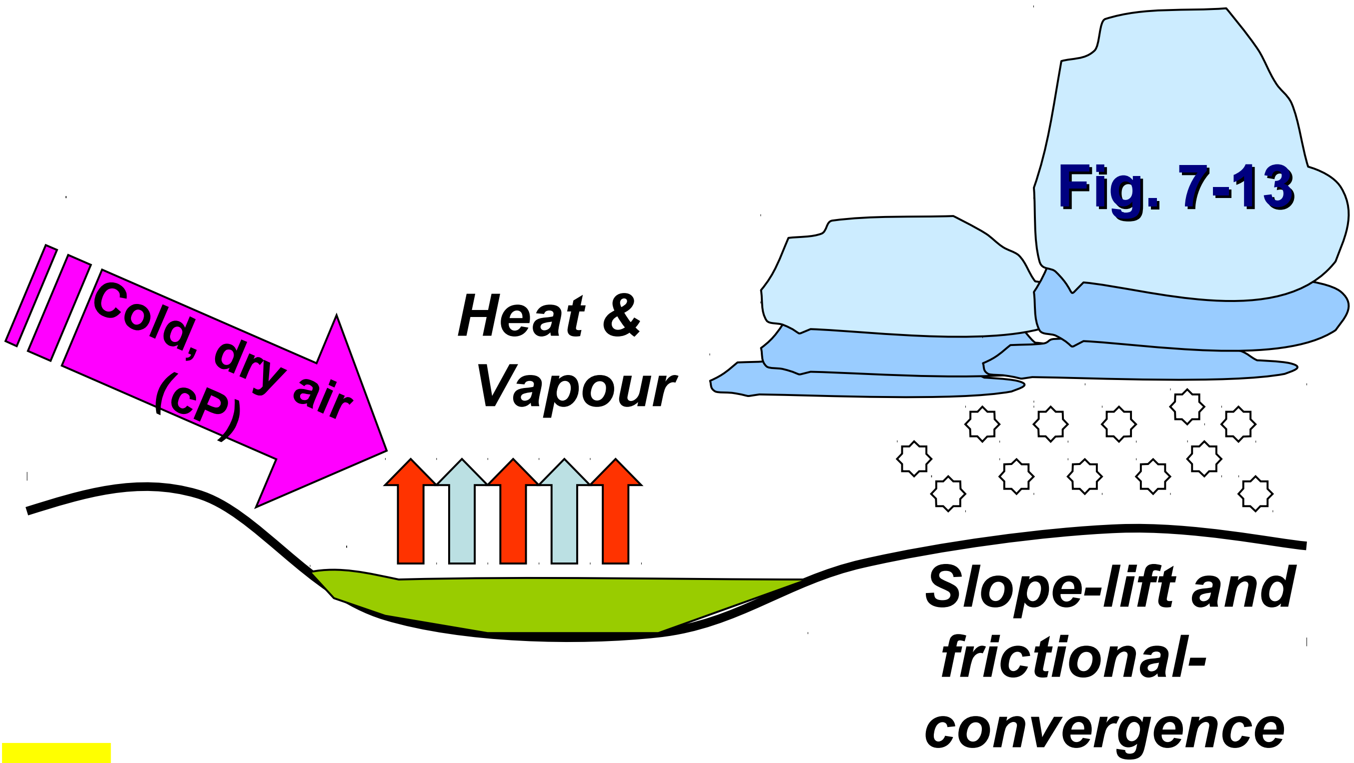
Lake-effect

Fig. 7-11a

LAKE-EFFECT SNOWS

- ice-free lake
- maximal $T_{\text{water}} - T_{\text{air}}$
- long overwater fetch





Sleet

• falling ice crystals or snowflakes melt upon falling into warmer air, then the resulting raindrops re-freeze

• note the surface inversion that is associated with this

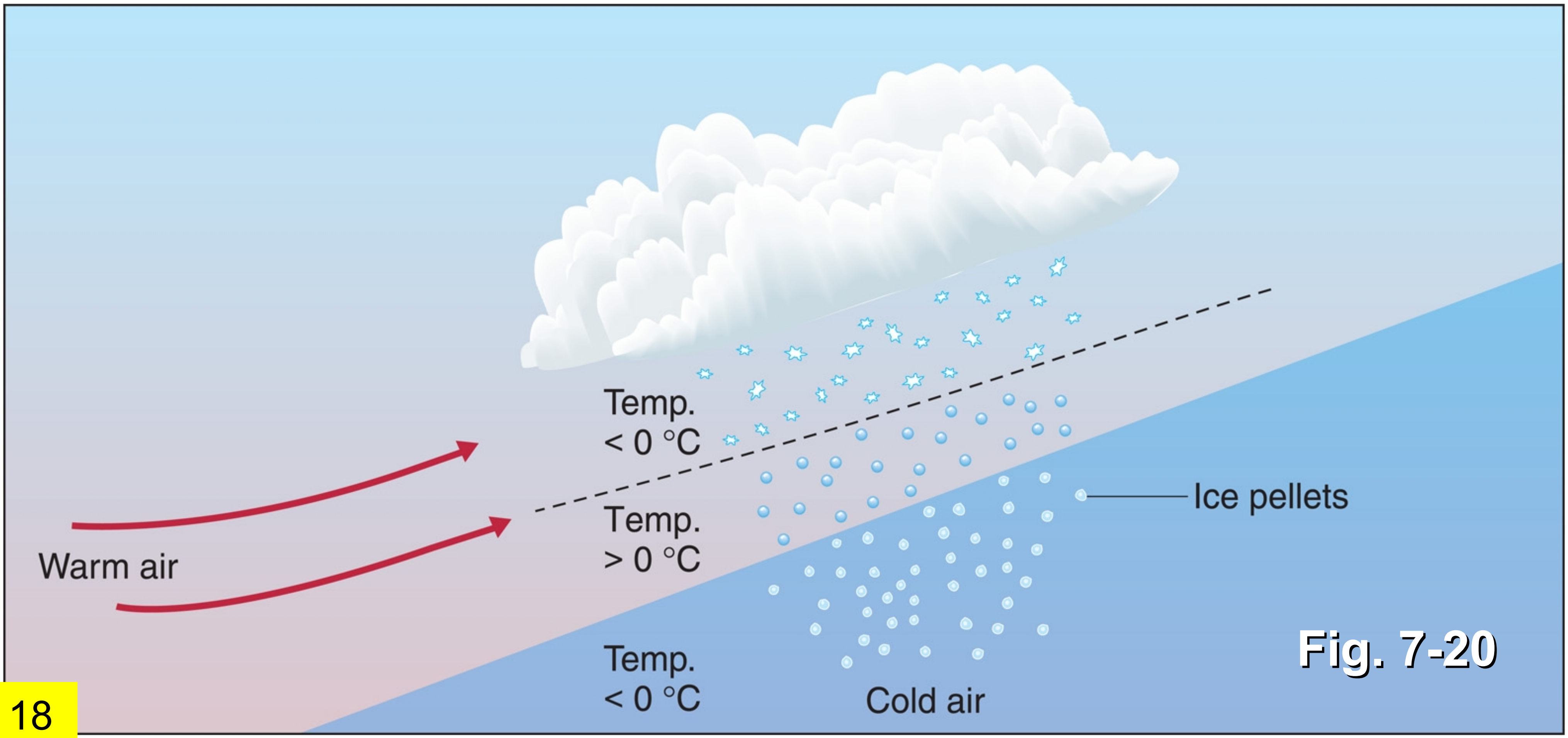


Fig. 7-20

Freezing rain

• light rain of supercooled droplets falling through a near-ground layer at or just below the freezing temperature