Ch15. Weather Forecasting: will emphasize NWP

EAS270_Ch15_WeatherForecasting.odp
JDW, EAS Ualberta, last mod. 6 Dec. 2016

We have already covered much of Chapter 15, e.g. surface and upper-air maps

Photo courtesy of E. Hudson, Prairie & Arctic Aviation Weather Centre, Edmonton

Beginning of modern era: mid-1800s, telegraphy used to quickly communicate weather data from afar, permitting to see and analyse patterns and form theories

Recall we distinguish:

- analysis (of present state of the atmosph.)
- forecast (prognosis) of future state

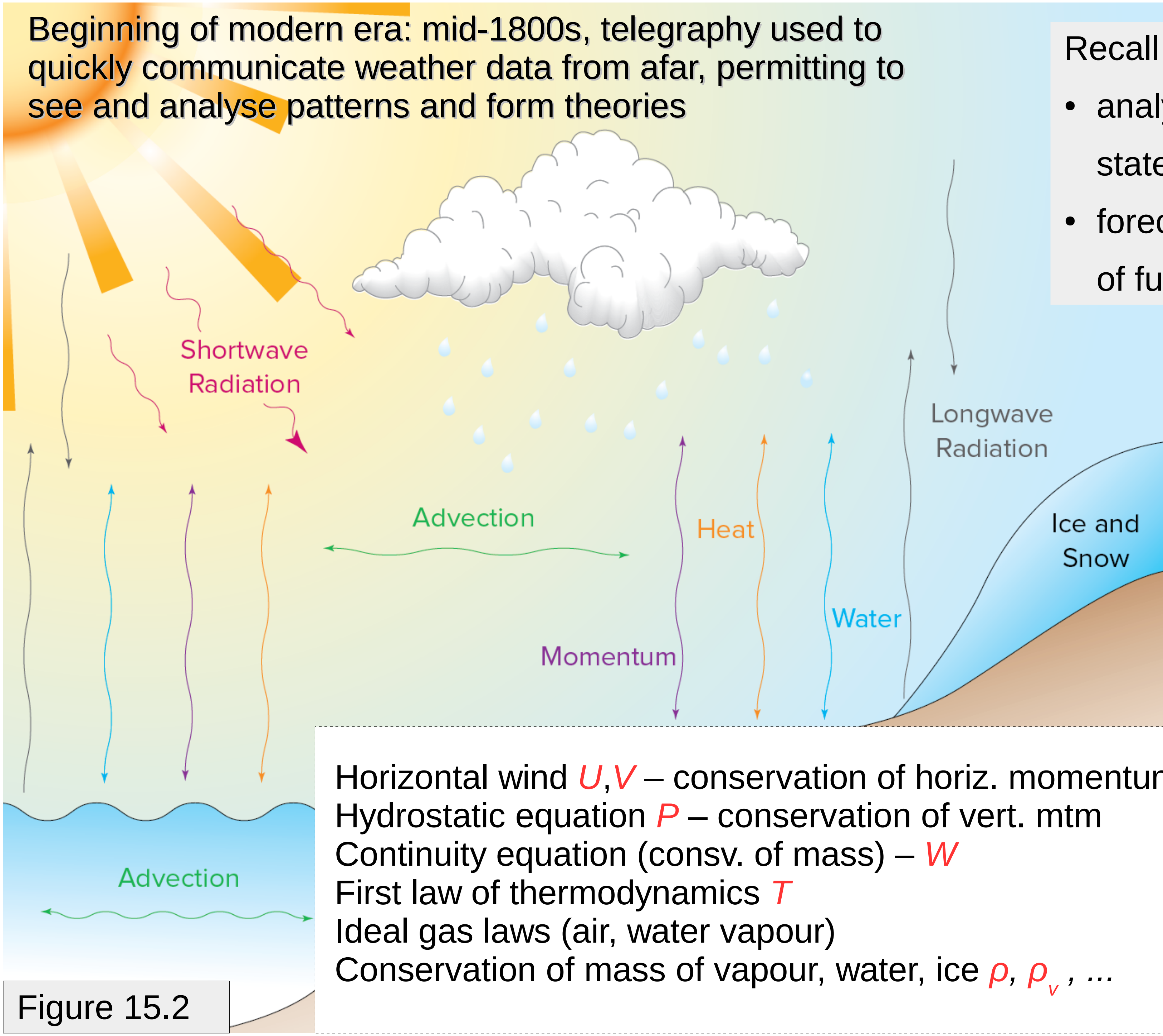


Figure 15.2

Horizontal wind U,V – conservation of horiz. momentum (force balance)
Hydrostatic equation P – conservation of vert. mtm
Continuity equation (consv. of mass) – W
First law of thermodynamics T
Ideal gas laws (air, water vapour)
Conservation of mass of vapour, water, ice ρ, ρ_v , ...

PERSISTENCE (+ "trend")

- future weather the same as present weather, (with allowance for any trend)
- difficult to beat for short range fcst, e.g. this afternoon's weather same as this morning's, except for influence of local processes (eg. solar heating)
- reliability decreases with increasing forecast range

ANALOG METHODS (PATTERN RECOGNITION)

A set of weather maps that characterize the meteorology of the region of interest (see over)

- hinges on using past experience, e.g. weather map "types"
- an obsolete approach, far surpassed by modern NWP

CLIMATOLOGICAL METHODS (could also be termed "statistical")

- hard to beat for a forecast range beyond about two weeks
- e.g. today's max temperature in Edmonton will equal the mean daily max observed 1981-2010 for Dec. in Edmonton City (-4.5°C)
- or, forecast the anomaly associated with (eg.) Southern Oscillation Index

NWP

- integrate governing equations to ***objectively*** deduce future state from present

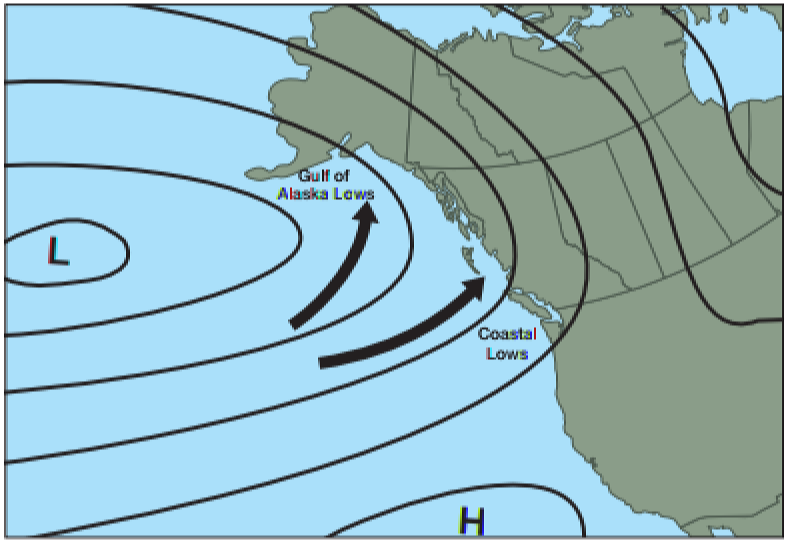


Fig. 3-7 - Principal winter storm tracks are superimposed on a January mean sea-level pressure pattern

Of course one would include other map types, but not too many.

Gulf of Alaska Lows

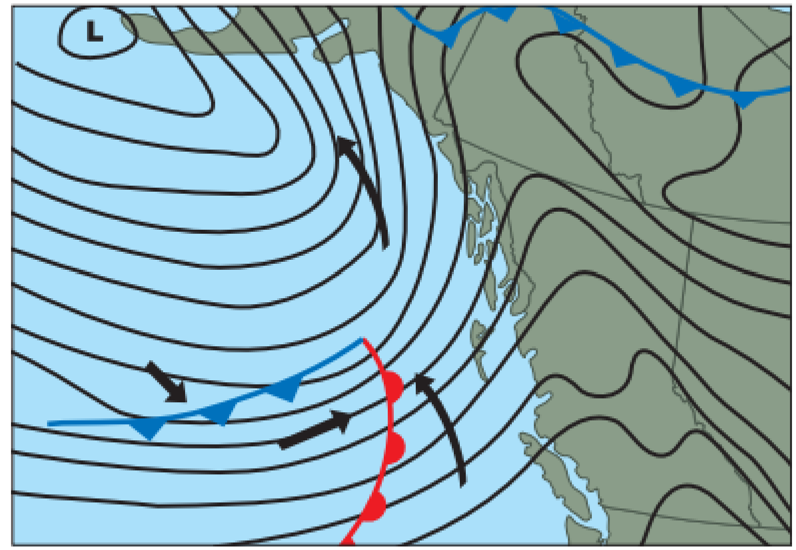


Fig. 3-8 - This sea-level pressure pattern indicates a Gulf of Alaska low with the associated frontal system approaching the B.C. coast

A **Gulf of Alaska low** usually forms south of the Aleutians as a frontal wave between the cold northern air and warmer air to the south. Such a wave may travel a considerable distance eastward before it begins to take shape as a low pressure system. Once the low starts to develop, pressures fall rapidly and the entire low pressure system increases in size. The low, travelling eastwards at typically 35 to 40 knots, reaches its lowest central pressure (970 hPA or lower) over the Gulf of Alaska then turns northeastward toward the northern end of the Alaskan Panhandle. The frontal system that accompanies the low continues eastward onto the coast, bringing widespread cloud, precipitation, and strong winds. Behind the cold front, a period of strong northwesterly winds of 35 to 50 knots heralds the arrival of a colder, unstable airmass.

Coastal Lows

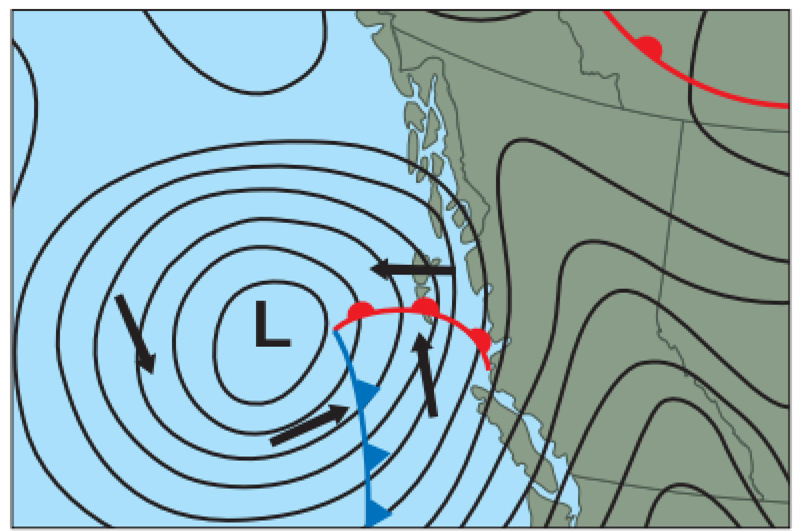
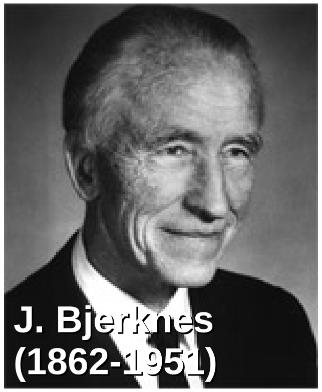


Fig. 3-9 - A typical sea-level pressure pattern for a coastal low and associated frontal system with wind pattern superimposed

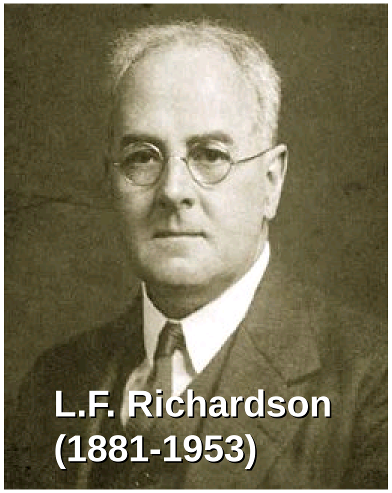
Coastal lows usually intensify very rapidly just before they move over the British Columbia coastal waters and can change from a very weak system into a severe storm in as little as 9 hours. Lows which do develop in such a rapid, or explosive manner, are referred to by the forecasters as “bombs.” On the coast, very strong winds will occur usually to the east and southeast of the low, just ahead of the associated frontal system. Winds here may reach southeasterly 70 knots with gusts to 100 knots in the most severe storms. Often, a second band of strong winds occur behind the cold front in the area to the southwest of the low pressure centre. Here, winds may range up to 65 knots from the west or northwest. Once the low moves ashore, it will fill rapidly over the Coast Mountains and frequently dissipate before penetrating very far into the interior...



Bjerknes (1904): "If it is true, as every scientist believes, that subsequent atmospheric states develop from the preceding ones according to physical law, then it is apparent that the necessary and sufficient conditions for the rational solution of forecasting problems are:

1. A sufficiently accurate knowledge of the atmosphere at the initial time
2. A sufficiently accurate knowledge of the laws according to which one state of the atmosphere develops from another

Weather forecasting is an "initial value problem." Bjerknes identified 7 interconnected variables (U, V, W, P, T, ρ , ρ_v) needing to be known, and 7 independent equations

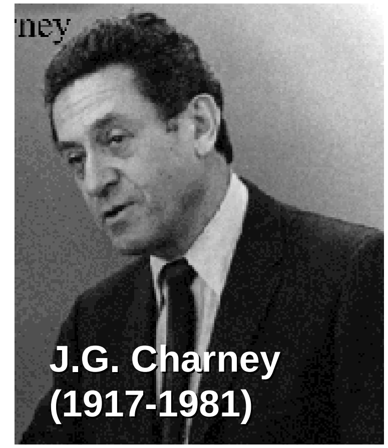


Richardson: Quaker. Graduated Cambridge; worked for National Peat Industries (solved eqns. relating to drainage); joined U.K. Met. Office 1913 as superintendent of a remote observatory; resigned 1916, volunteered as ambulance driver, WW1 France; in off-duty time, embarked on test of his mathematical weather forecasting method. Had taken with him to France observations for 7 a.m., 20 May 1910. By 1916, had written wrote *Weather Prediction by Numerical Process*, not published until 1922

The forecast was a huge achievement, but was very inaccurate.

It had been ruined by the growth of non-meteorological scales of circulation

- 1930s and on: development of a simplified set of equations suitable for numerical integration: the "quasi-geostrophic paradigm"(*) of Rossby, Eady, Charney, Phillips, and others [eqns that do not permit acoustic waves and gravity waves]
- 1930s: development of radiosondes for upper air observations
- 1940-50s: emergence of digital computer (weather forecasting a priority)
- 1960s and on: satellite observations, weather radar



(*) formulated in vorticity ζ_r and divergence D, rather than velocities

The 1970s saw a return to models formulated in u, v

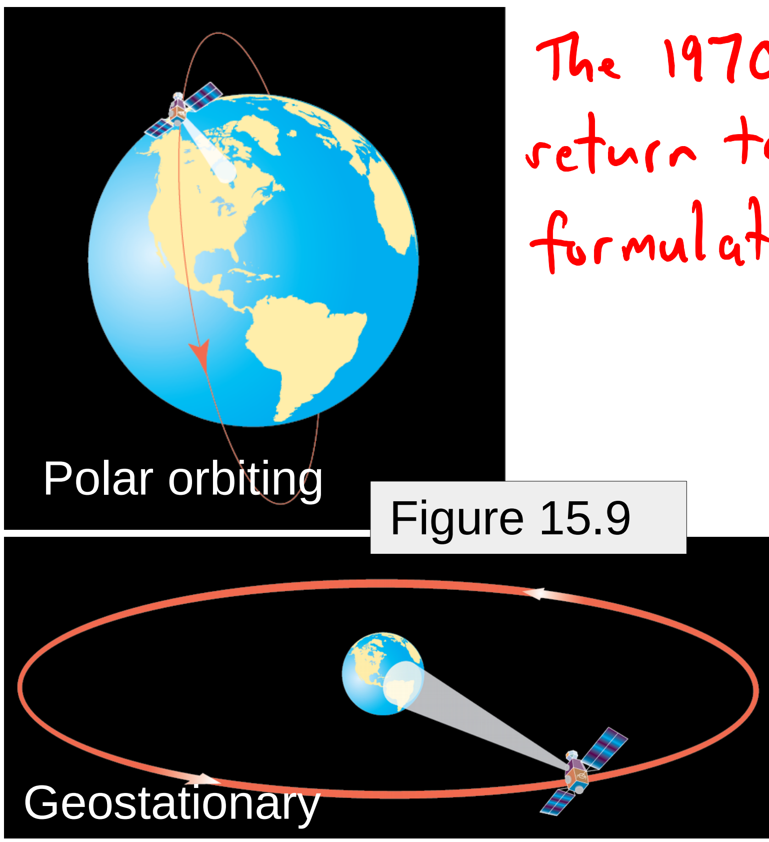


Figure 15.9

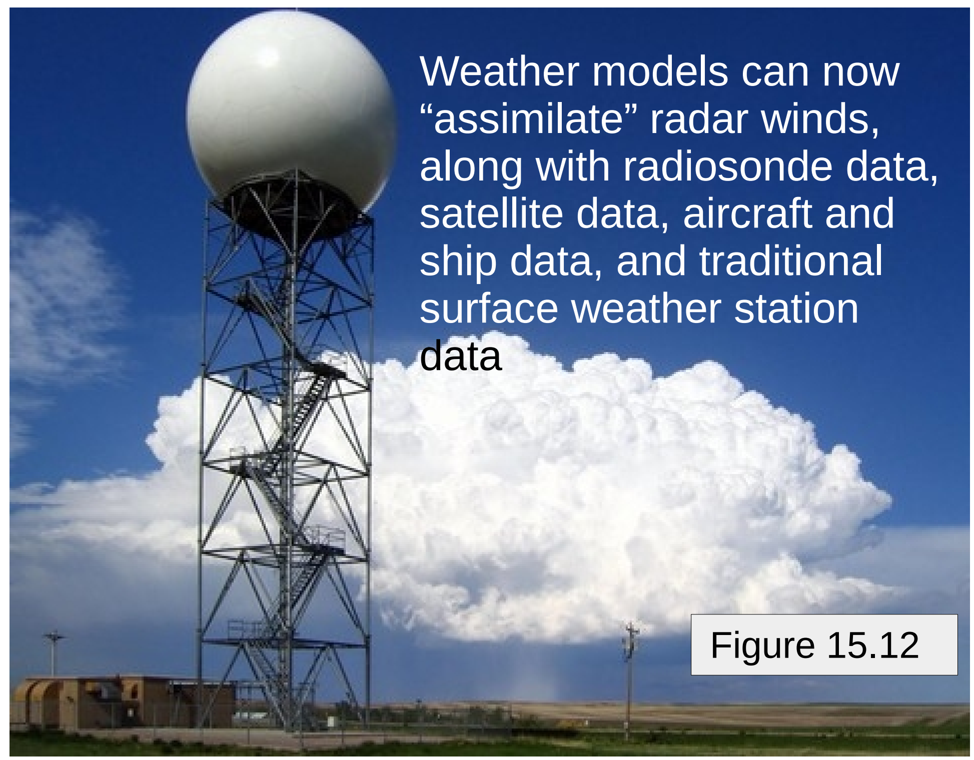


Figure 15.12

Forecast range (i.e. "lead time")

Nowcast – forecast range very short (up to about 6 hours)

Short range forecast – about 12 hours to 3 days

Medium range forecast – from about 3 to about 7 or more days

Long range forecast – beyond about 2 weeks

fuzzy boundaries

Forecast skill

Meteorological forecasts are defined have skill only provided that – on average – they are more accurate than a forecast based on persistence or a forecast based on climatology

Tools available for (causal) short & medium range forecasting

Observations (surface analysis, 850 isobaric chart, etc., soundings, satellite images, radar images) – all bearing on *present* weather

+

Numerical weather forecasts (prognoses or "progs")

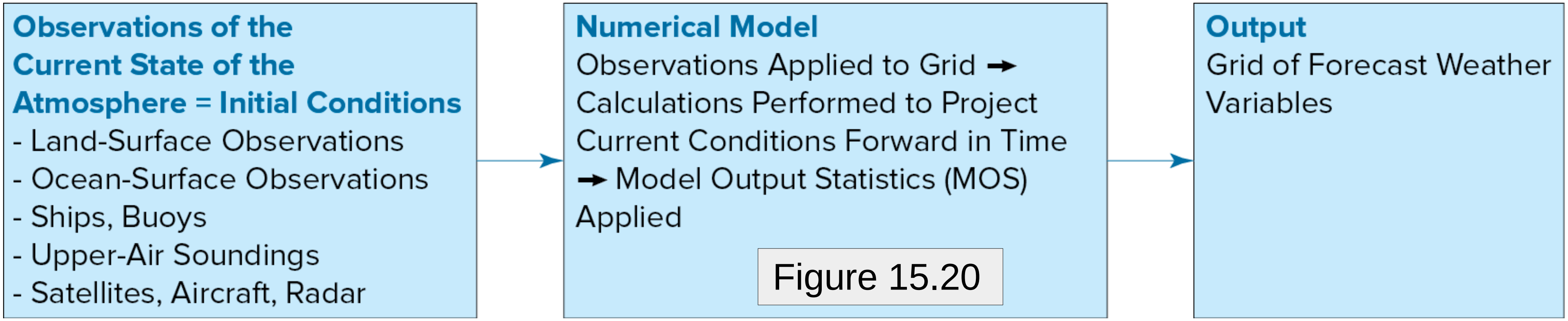


Figure 15.20

more detail next page

Today's NWP models are skillful (see previous definition) for forecast ranges from about 12 hours to two weeks – the skill decreasing with increasing range

At long range, NWP model "forgets" initial conditions but – provided model is "driven" by correct external variables (solar constant, atmospheric CO_2,...) – it should produce correct climate the "synoptic times"

time t_0

Observations
– global scope –
00, 06, 12, 18 GMT
+ continuous satellite obs + irregularly timed ship/aircraft reports

Analysis valid at t_0

00, 06, 12, 18 GMT

e.g. at CMC (Cdn Meteorol. Centre, Montreal)

Forecast ("prognosis")

(Guides human forecasters)

Forecast initialized at t_0-6 hrs, and valid at time t_0

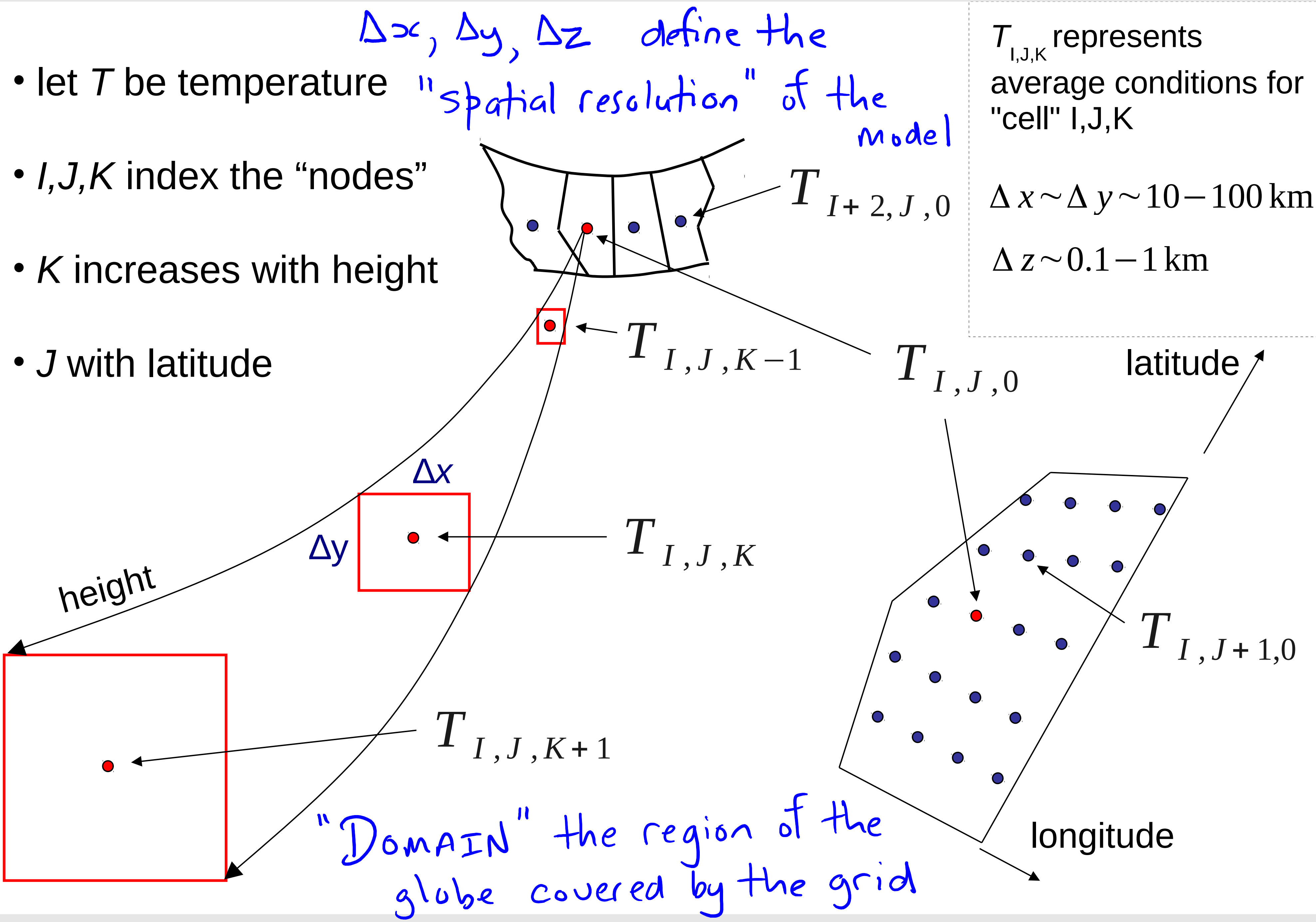
The "analysis" interpolates observations onto a 3-dimensional "grid", and blends the data with a forecast from a few hours earlier – providing "initial conditions" for the model forecast

- let T be temperature
- I,J,K index the "nodes"
- K increases with height
- J with latitude

$T_{I,J,K}$ represents average conditions for "cell" I,J,K

$\Delta x \sim \Delta y \sim 10-100\,\mathrm{km}$

$\Delta z \sim 0.1-1\,\mathrm{km}$



** i.e. a "gridded" representation of the atmosphere in 3D. A "node" is a "gridpoint"

Computational power limits how small we can choose $(\Delta x, \Delta y, \Delta z)$ and Δt

CMC's model is GEM (Global Environmental Multiscale)

- RDPS (Regional Deterministic Prediction System): GEM is run 4 x daily in a “regional configuration” (limited area domain) for which the grid spacing over N. America is 10 km (5 min time step). "temporal resolution" Δt
- GDPS (Global Deterministic Prediction System): GEM is run 2 x daily in “global configuration” with a 25 km resolution over N. America (79 levels, 12 min time step).
- GEM based on physics as expressed in “governing equations” that are approximate statements of conservation of mass, momentum, energy + equations of state + (etc.)
- GEM's equations solved numerically, given “initial” and “boundary” conditions (eg. sea surface temperature + much more) A regional model requires some strategy to provide values on the lateral boundaries
- solution gives gridded fields of wind velocity (*U,V,W*), temperature *T*, humidity *Q*,... (3-dimensional view)
- in order for a forecaster to produce his/her public forecast, NWP guidance is (or may be) supplemented by rules of thumb, statistical packages (e.g. Model Output Statistics), subjective inputs (software SCRIBE helps with this process)

A "regional" model has a domain that does not cover the whole globle

Past NWP forecasts giving gridded predictions of wind, temperature, humidity,...

Past observations of specific weather elements at specific places, e.g. visibility *V* at 12Z at Edmonton Int'l Airport (CYEG)

Training phase

Statistical equation (correlation) relating the property of interest (e.g. visibility *V*) to a set of model output variables

A (bogus) example:

MOS model coefficients are tuned

$V = 0.87 (T - T_d)_{850} + 0.5 Z_{500} \ldots$

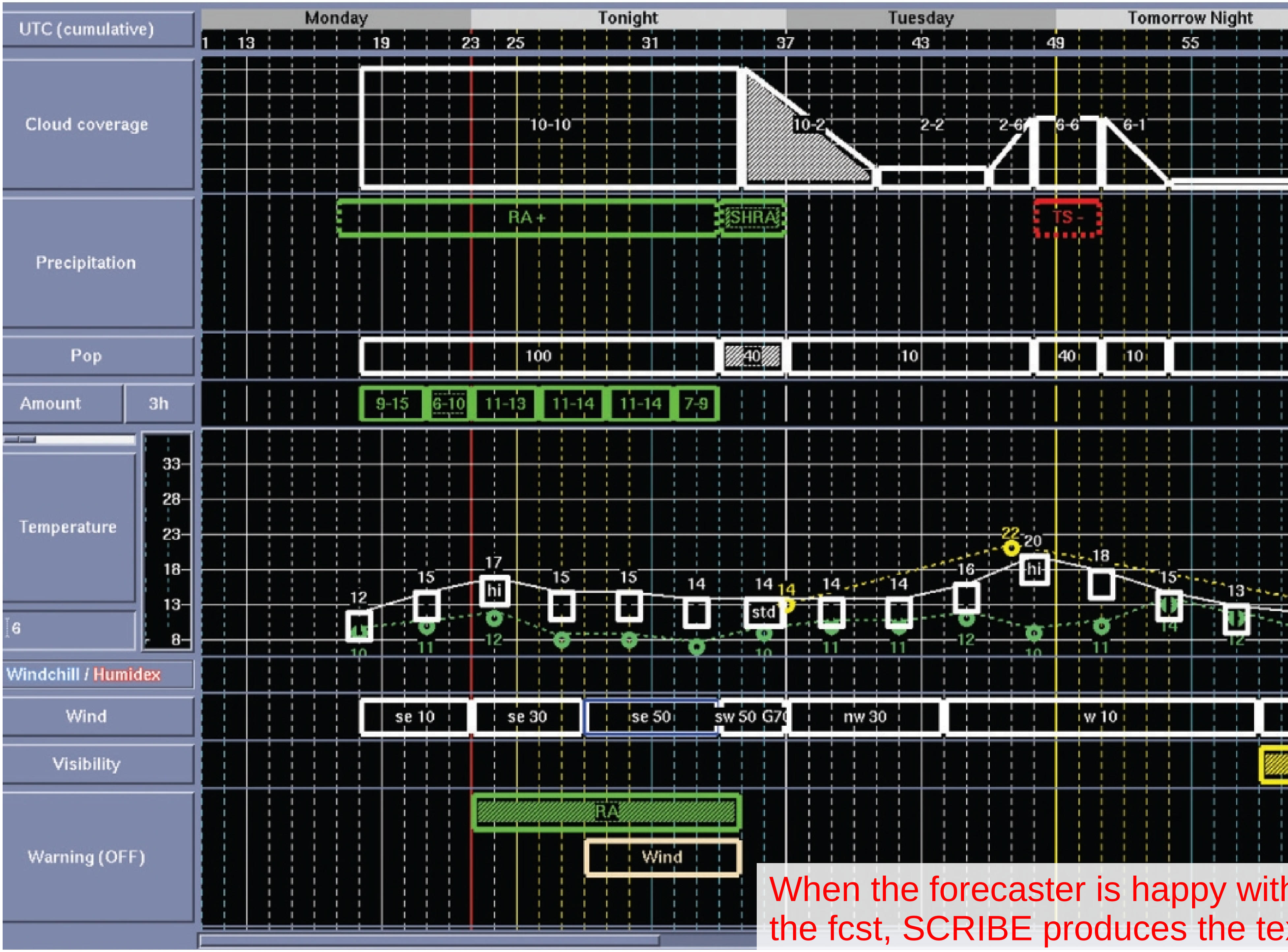
from NWP model

Operational phase

Latest NWP forecast giving gridded predictions of wind, temperature, humidity,...

V = ...

Visibility forecast for 12Z at Edmonton Int'l Airport (CYEG)



When the forecaster is happy with the fcst, SCRIBE produces the text

Extreme sensitivity to initial conditions

– "slight differences in initial conditions can produce quite different forecasts... errors in initial conditions amplify over time." (Limits range of skillful weather forecasts; at long range, weather model should have correct *climate*)

Idealizations (approximations, simplifications) in the governing equations

- e.g. use of the hydrostatic equation rather than full W-mtm eqn

(modern non-hydrostatic NWP models use a more complete vertical mtm eqn)

Sparsity of data inputs for initialization (over some regions; satellites help)

Limited area of coverage (model "domain") – non-issue for global models

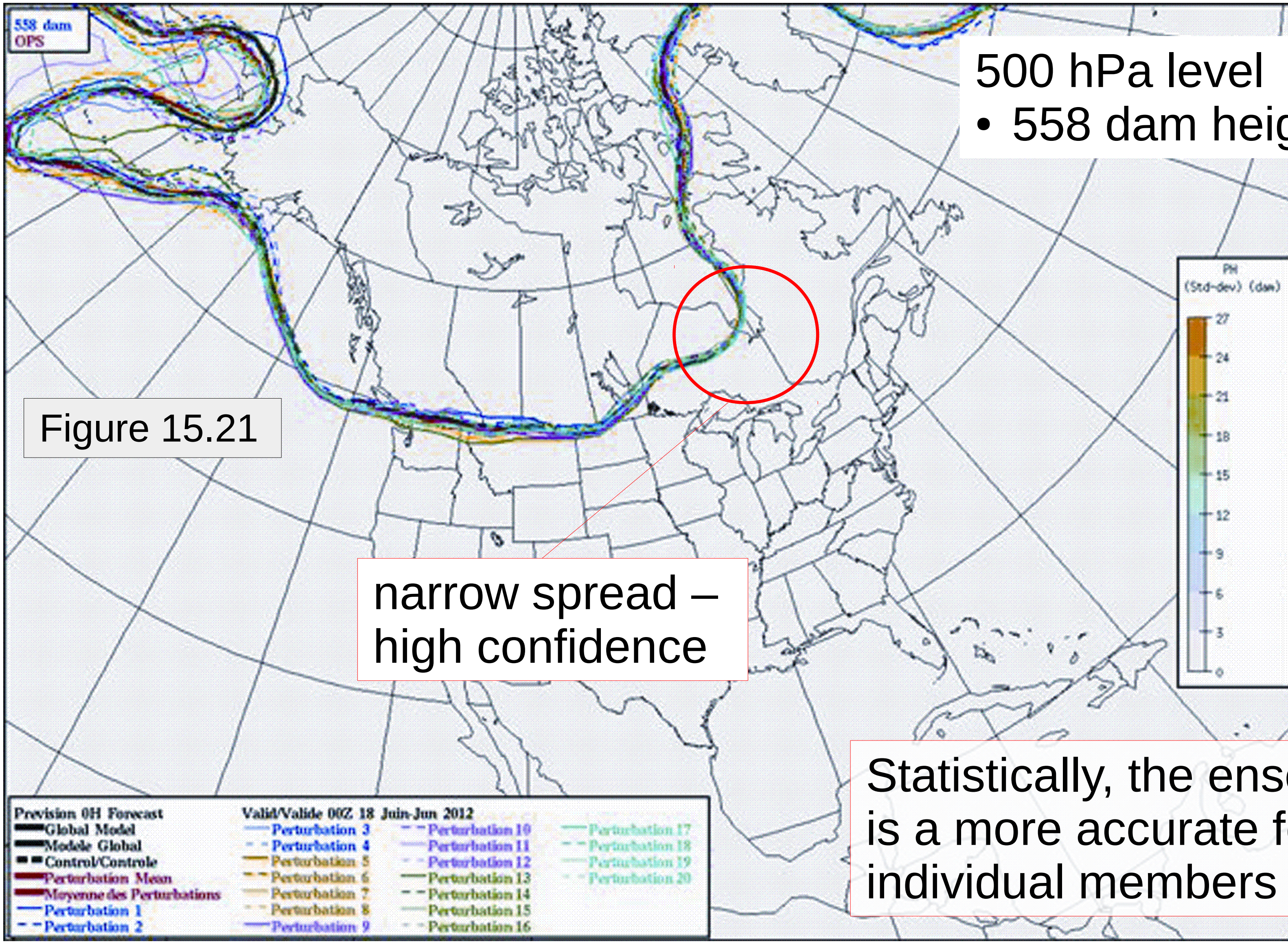
"subgrid"

Treatment of small scale processes (i.e. smaller than the grid spacing)

"unresolved"

- "parameterizations" represent the small scale processes in terms of variables that *are* resolved by the model, i.e. values on the grid

- example: individual Cu have diameter *d* << 10 (or 25) km, the resolution provided by (grid spacing of) GEM. The "convective parameterization" lets a layer of air overturn and mix if appropriate, i.e. depending on model temperature lapse rate (conditionally unstable?) and humidity of the layer



500 hPa level

- 558 dam height contour

Figure 15.21

narrow spread – high confidence

Statistically, the ensemble average is a more accurate forecast than the individual members

20 runs of GEM global, each with slightly different initial conditions representing the state of the atmosphere at the initial time (sometimes the ensemble is composed of runs with *different models* as well as runs with different initial conditions)

Forecasting the precise location (and time) where a tornado will form is presently beyond modern forecasting techniques, but a general area of where a severe storm (capable of breeding a tornado) is likely to form can often be predicted up to three days in advance

Why?

- the scale of a tornado is far smaller than model grid spacing
- but, tornadoes can only form in the right kind of mesoscale and synoptic scale environment, and that larger scale setup *can* be skillfully forecast

Therefore best prospect for tornado warning is to use doppler radar to monitor for severe storms that exhibit a rotating updraft (mesocyclone) – short lead time for warnings

- do we wish to make highly specific predictions? – unlikely to be skillful due to extreme sensitivity to initial conditions

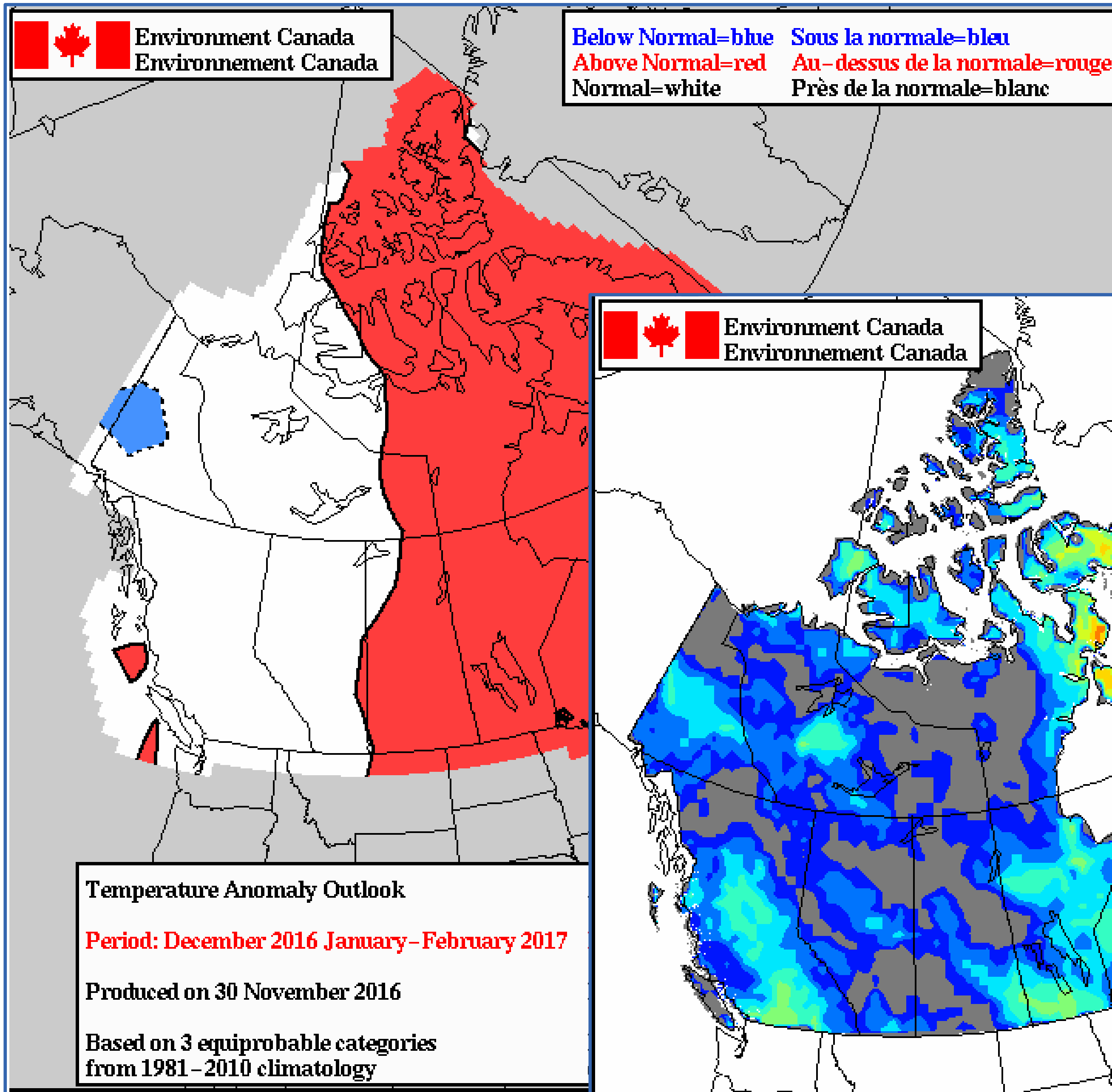
- or broader predictions of a persisting anomaly over (say) the 3 months to come, relative to (say) the 30-year climatology?

- MSC issues monthly and seasonal “deterministic” (NWP) and “probabilistic” (purely statistical) forecasts. These give the predicted anomaly in temperature and precipitation (three historically equi-probable categories: normal, below, above)

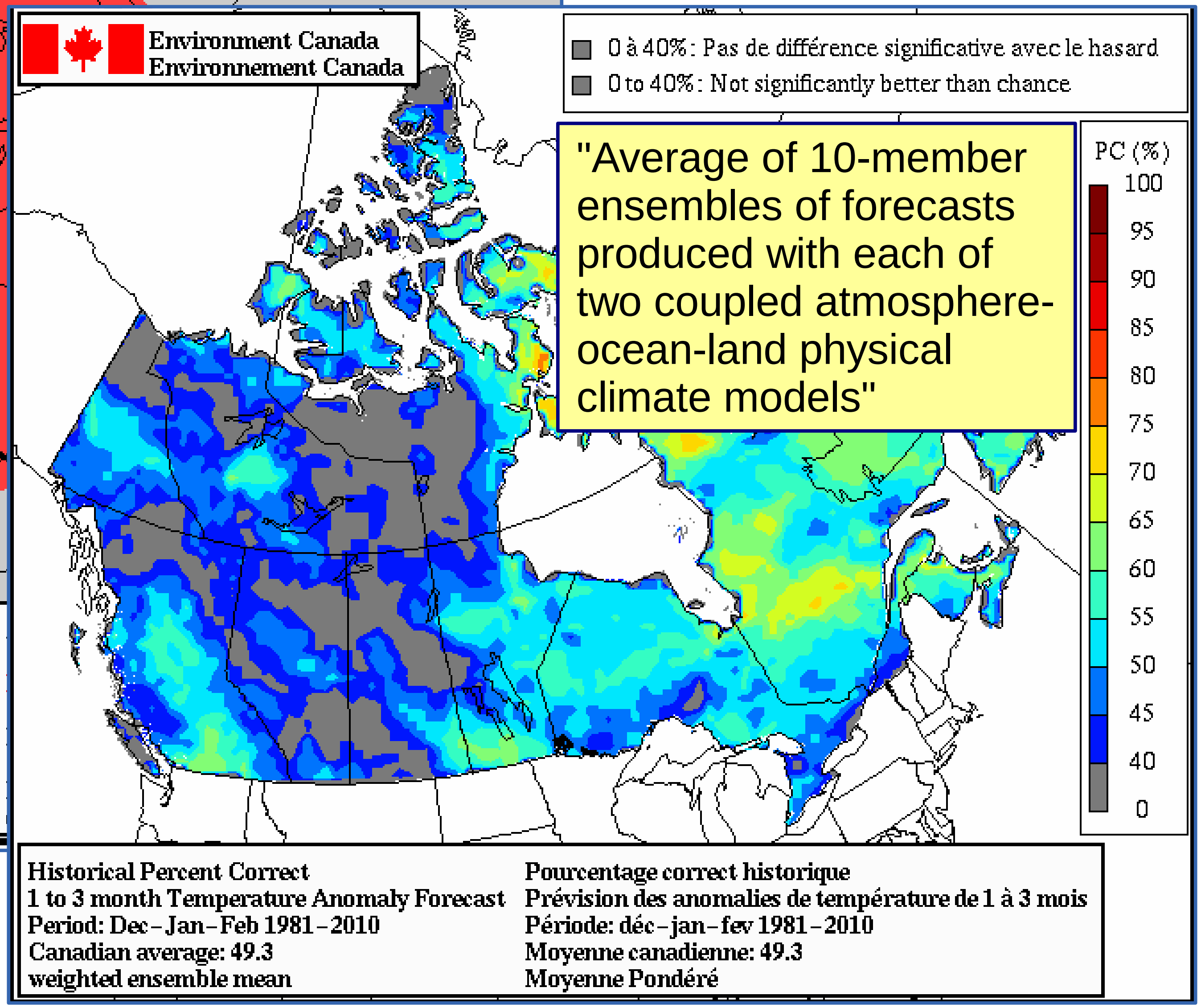
- historically the skill is low – but significant in some regions

- the origin of the skill (in both types of seasonal fcst) is probably the “teleconnections” associated with ENSO (El-Nino Southern Oscillation), i.e. a response to equatorial Pacific sea-surface temperature anomaly

**Weather forecasting is an “initial value problem”, climate forecasting is an “equilibrium problem” – e.g. how will climate re-adjust to a new equilibrium upon a doubling of atmospheric CO2 concentration?



This is a deterministic ensemble forecast: the model(s) were run forward through February 2017



"Average of 10-member ensembles of forecasts produced with each of two coupled atmosphere-ocean-land physical climate models"

Topics/concepts covered

- Elements of the history of modern weather forecasting
- Classification of methods for weather forecasting, and of forecast range
- Variables and equations used for NWP
- Grid for NWP
- Initialization
- Role of “parameterizations”
- Canada's GEM model (resolution, time step, domain, range)
- Model output statistics
- Basis for judging forecast “skill”
- Reasons for imperfection of NWP
- Seasonal forecasting