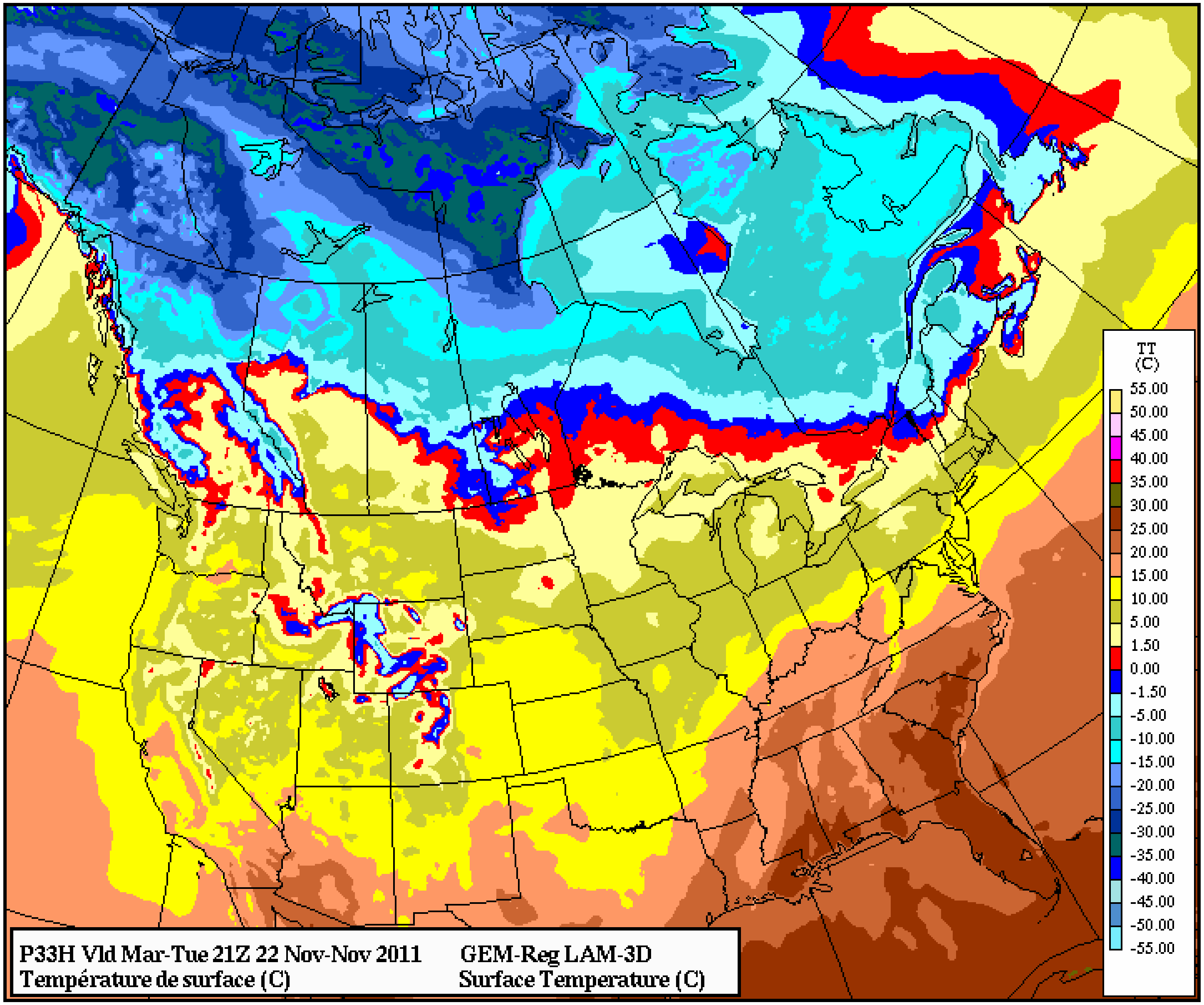
Goals for today

23 Nov. 2011

- Discuss Tuesday's mild weather
- Continue: Weather Forecasting & Analysis” (Ch. 13 + Appendix)

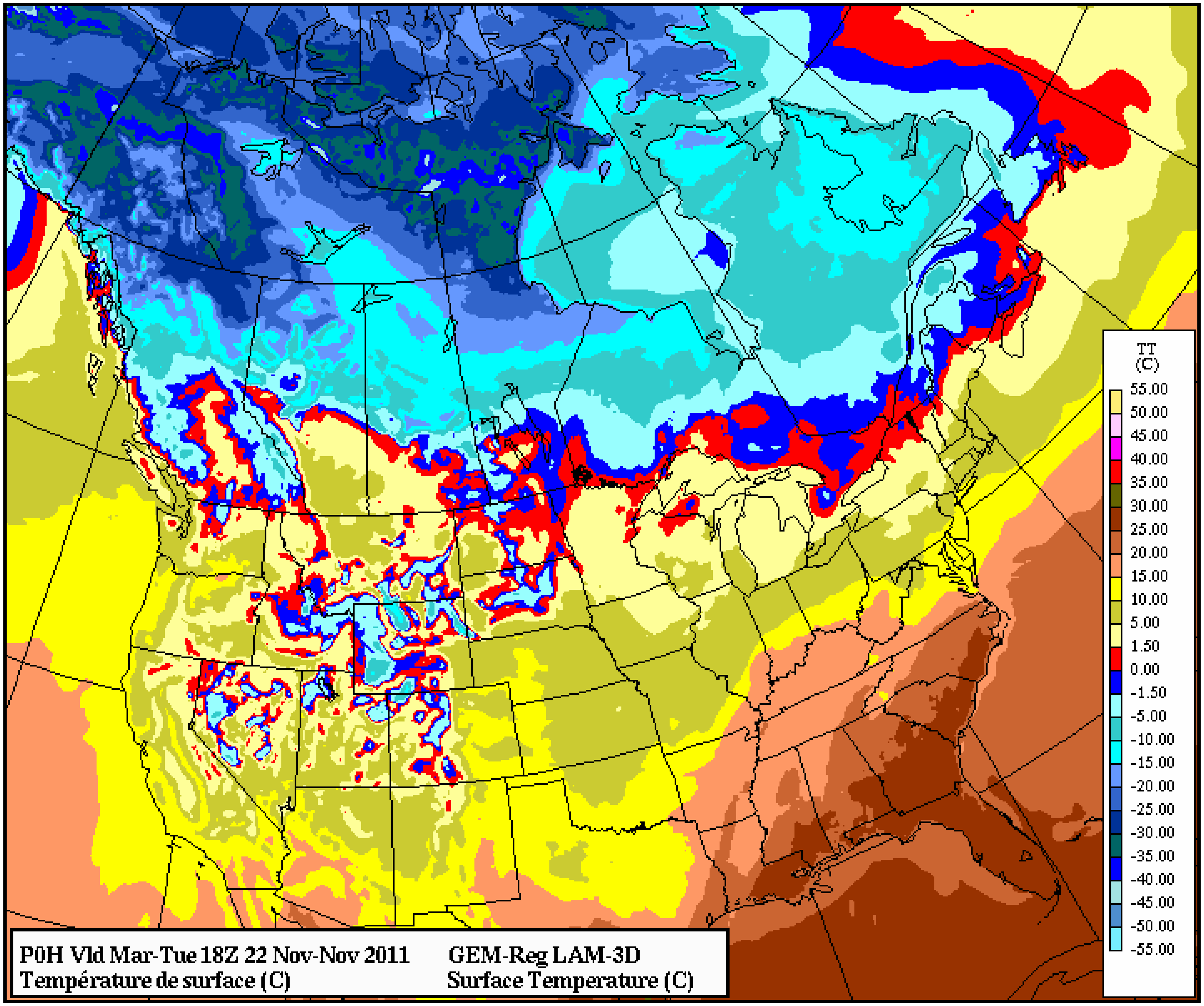
- Data acquisition
- Analysis phase
- Initialisation ($t = t_0$)
- Prediction phase (numerical integration)
- Post-processing phase

Monday's class included this MSC 33-hr forecast valid 21Z Tues 22 Nov. How good was it?



Weather services don't perform an analysis for 21Z – see next page, the 18Z analysis

File from Monday's class gave MSC 33-hr forecast valid 21Z Tues 22 Nov. How good was it?

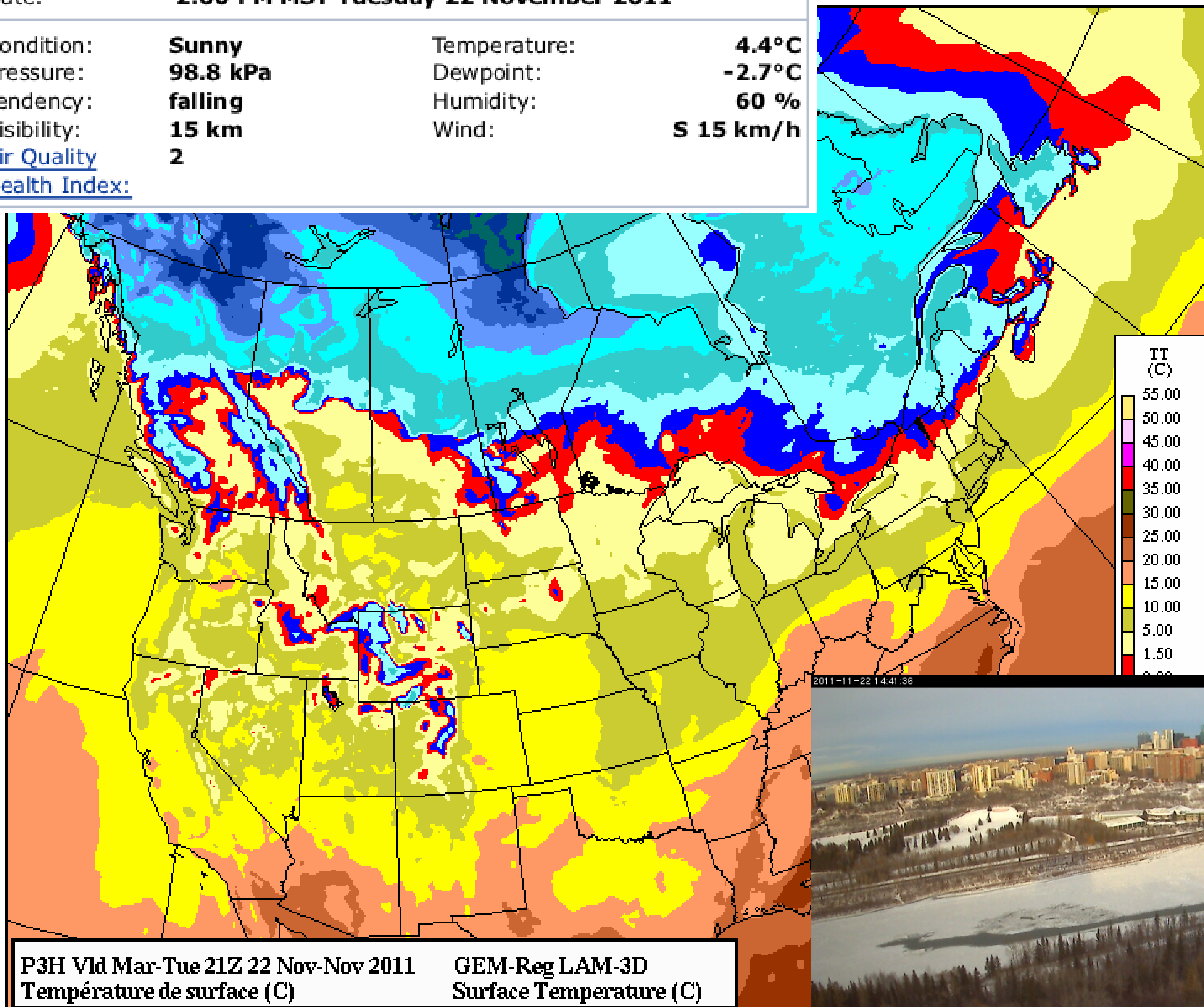


Weather services don't perform an analysis for 21Z – see next page, the 3 hr fcst valid 21Z

File from Monday's class gave MSC 33-hr forecast valid 21Z Tues 22 Nov. How good was it?

4 °C

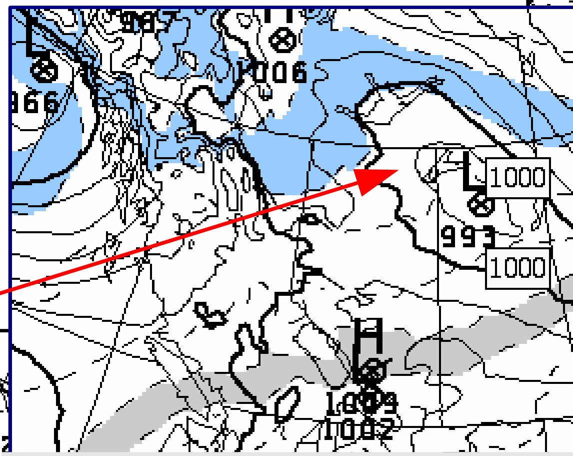
Observed at:	Edmonton City Centre Airport		
Date:	2:00 PM MST Tuesday 22 November 2011		
Condition:	Sunny	Temperature:	4.4°C
Pressure:	98.8 kPa	Dewpoint:	-2.7°C
Tendency:	falling	Humidity:	60 %
Visibility:	15 km	Wind:	S 15 km/h
Air Quality Health Index:	2		



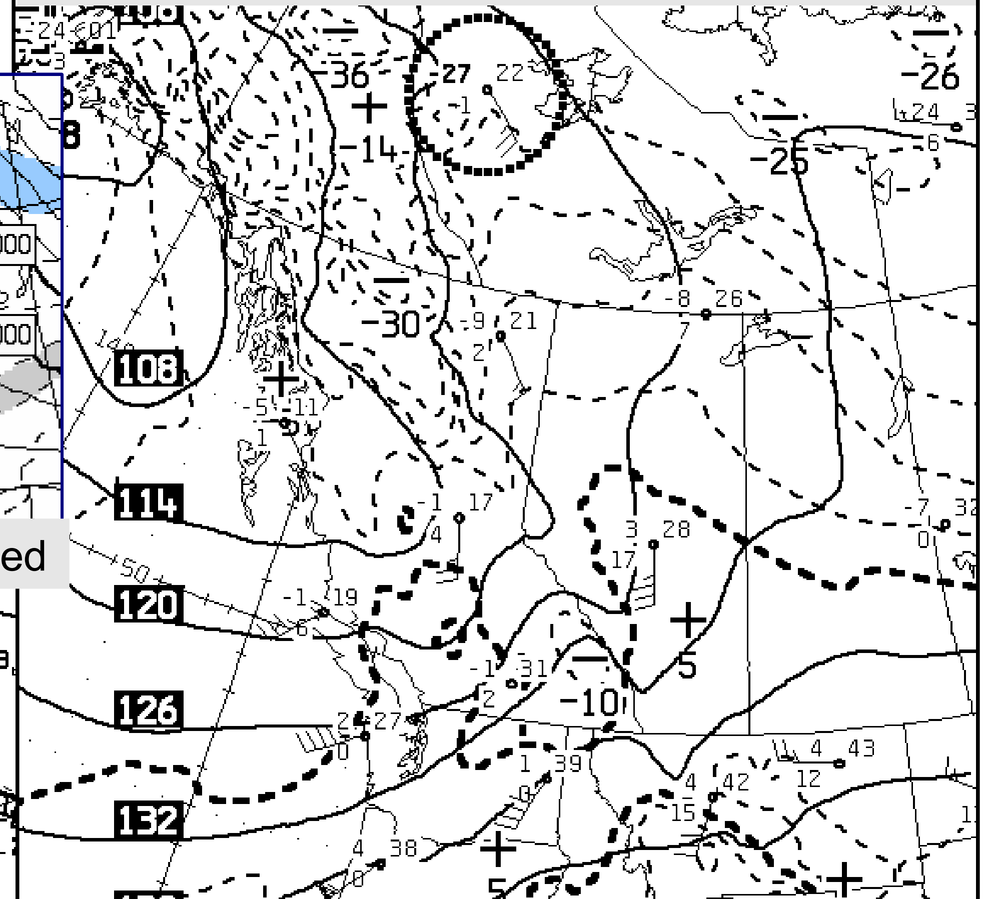
Very good resemblance to the 33-hr prog

Why so mild? – see over

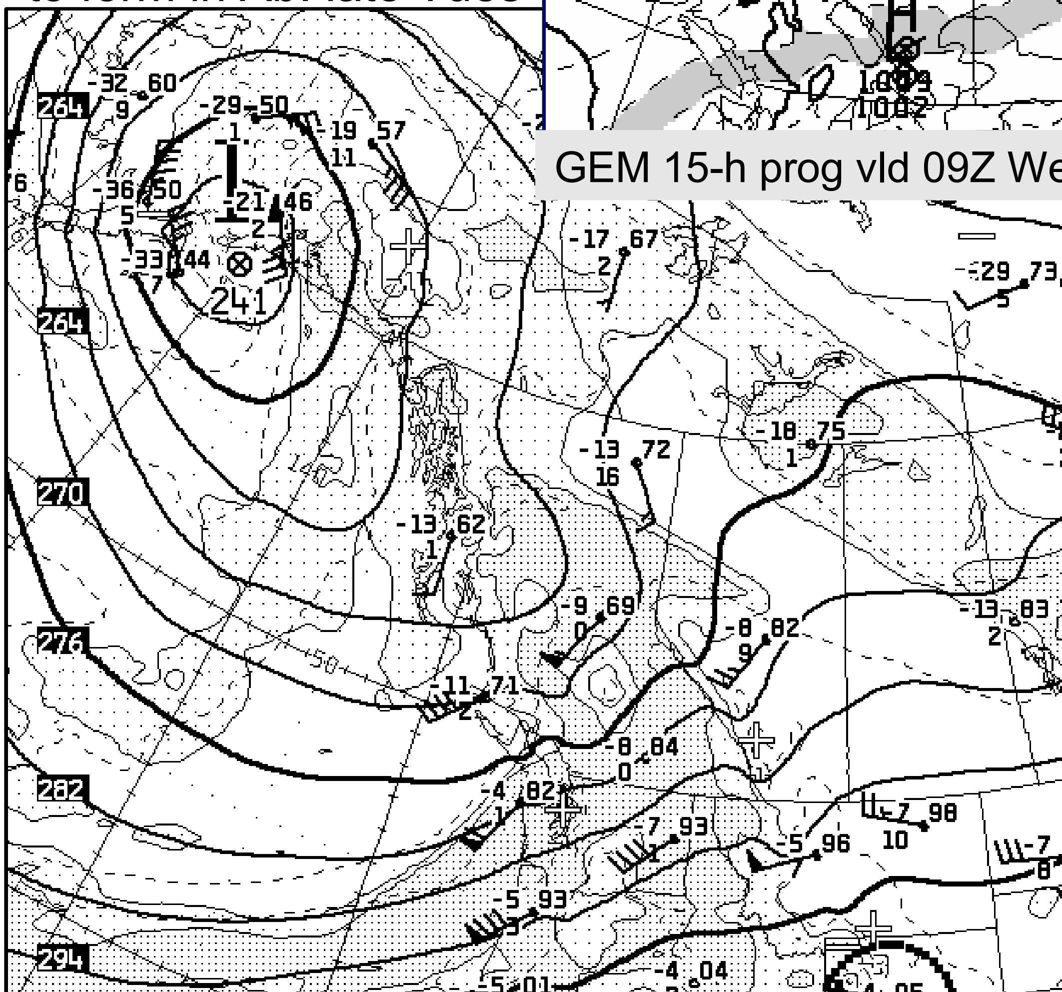
- offshore low advecting mild air to S. BC & Ab.
- SW flow aloft – lee trough
- a “lee low” is forecast to form in Ab. late Tues



GEM 15-h prog vld 09Z Wed

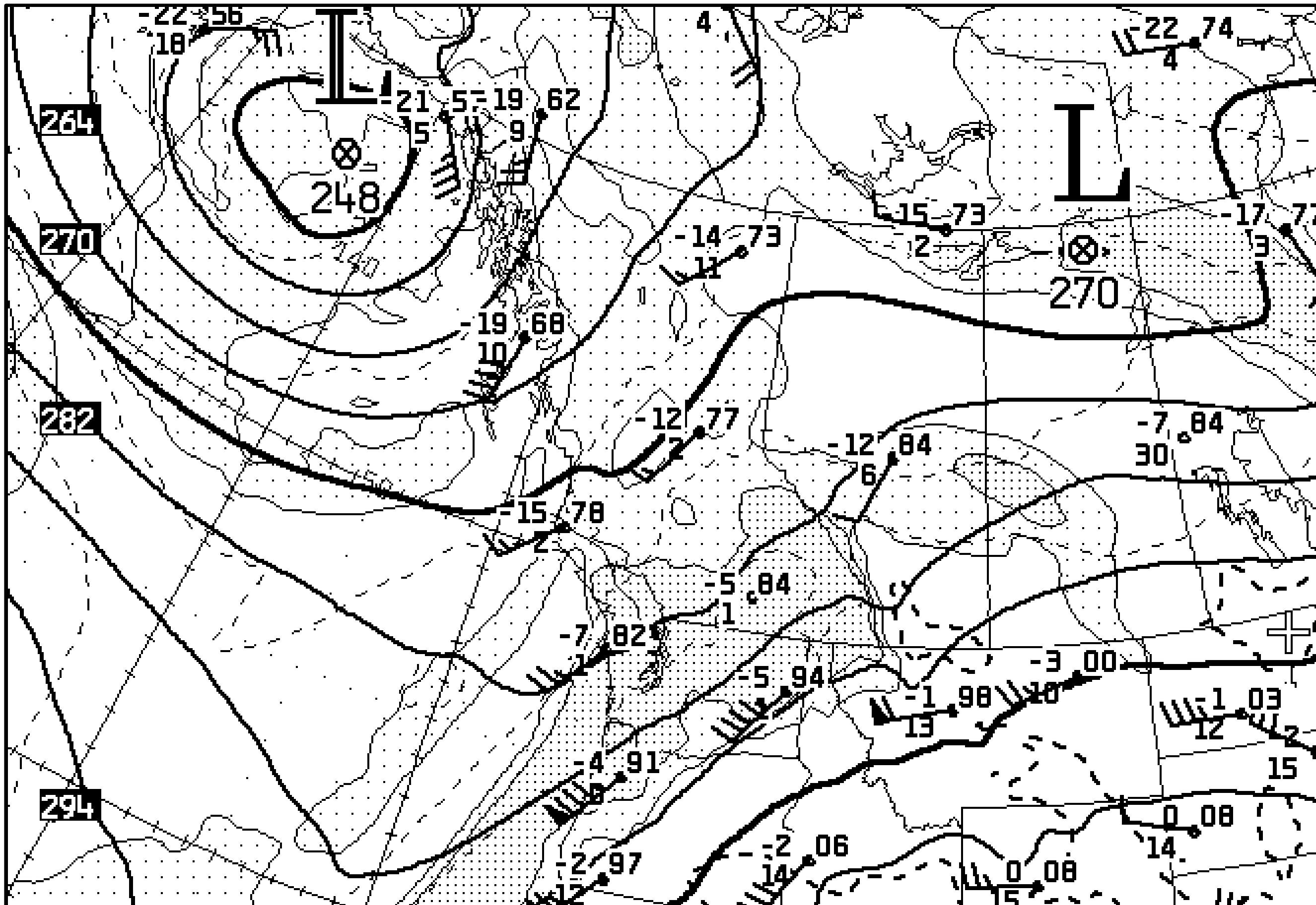


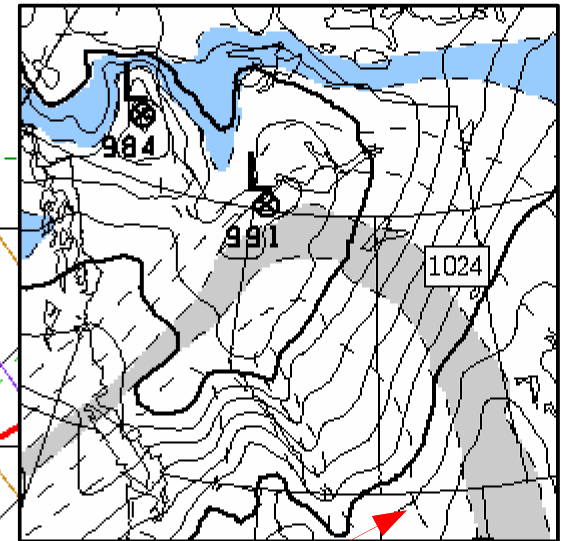
850 hPa analysis 12Z Tues 22 Nov. 2011



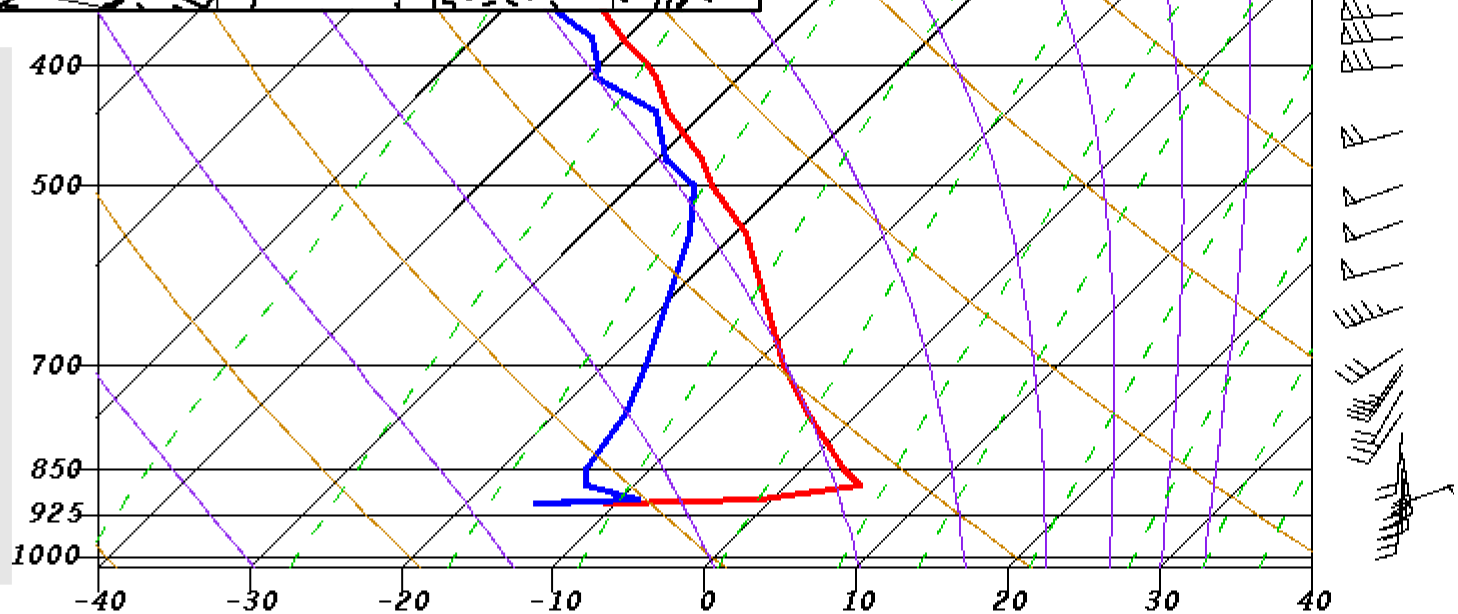
MSC 700 hPa analysis 12Z Tues 22 Nov. 2011

- formation of the lee low is often referred to as “lee cyclogenesis”
- often its a redevelopment/continuation of an existing Pacific storm that has arrived on the coast
- commonly the effect of a lee low is to sweep cold air back into Ab.





MSC GEM 90-hr prog for Sunday 06Z – more of same



Conditions 12Z today (23 Nov.):

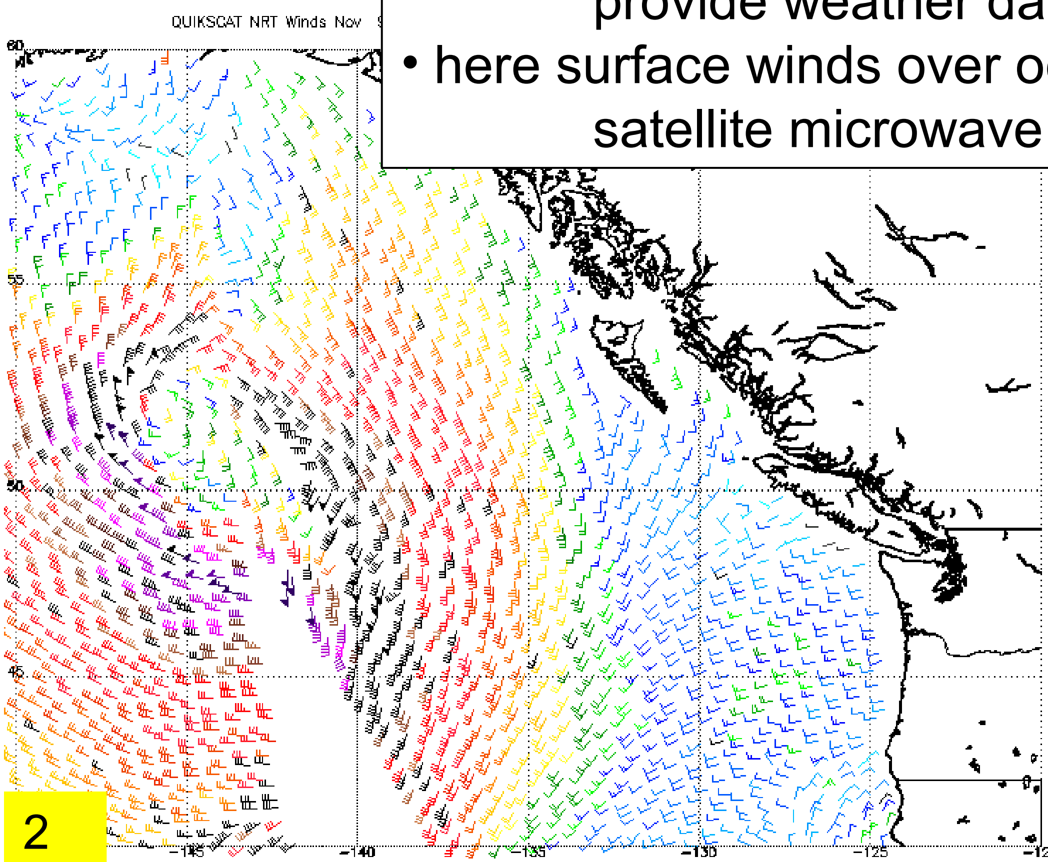
- SW current aloft

- Edmonton sounding shows very mild,dry air aloft above steep inversion

Data acquisition

- regional or global? (depending on f/c range)
- obs. coordinated by World Meteorol. Org.
- 10K land obs stations, 7K ship obs, 300 buoys, weather satellites, 1K radiosondes twice daily + sensors on scheduled commercial aircraft +…
- “synoptic times” 0000 and 1200 UTC (GMT), but increasing amount of data comes in off the synoptic times… challenge to incorporate these

- ever-improving technologies to provide weather data
- here surface winds over ocean from satellite microwave scatterometry



Doppler wind sounders (acoustic & electromagnetic)

Traditional in-situ synoptic data…

Rawindsonde
• a radiosonde tracked by radar

Automation – has a down side – e.g. stations measuring radiation need supervision to keep sensors clean

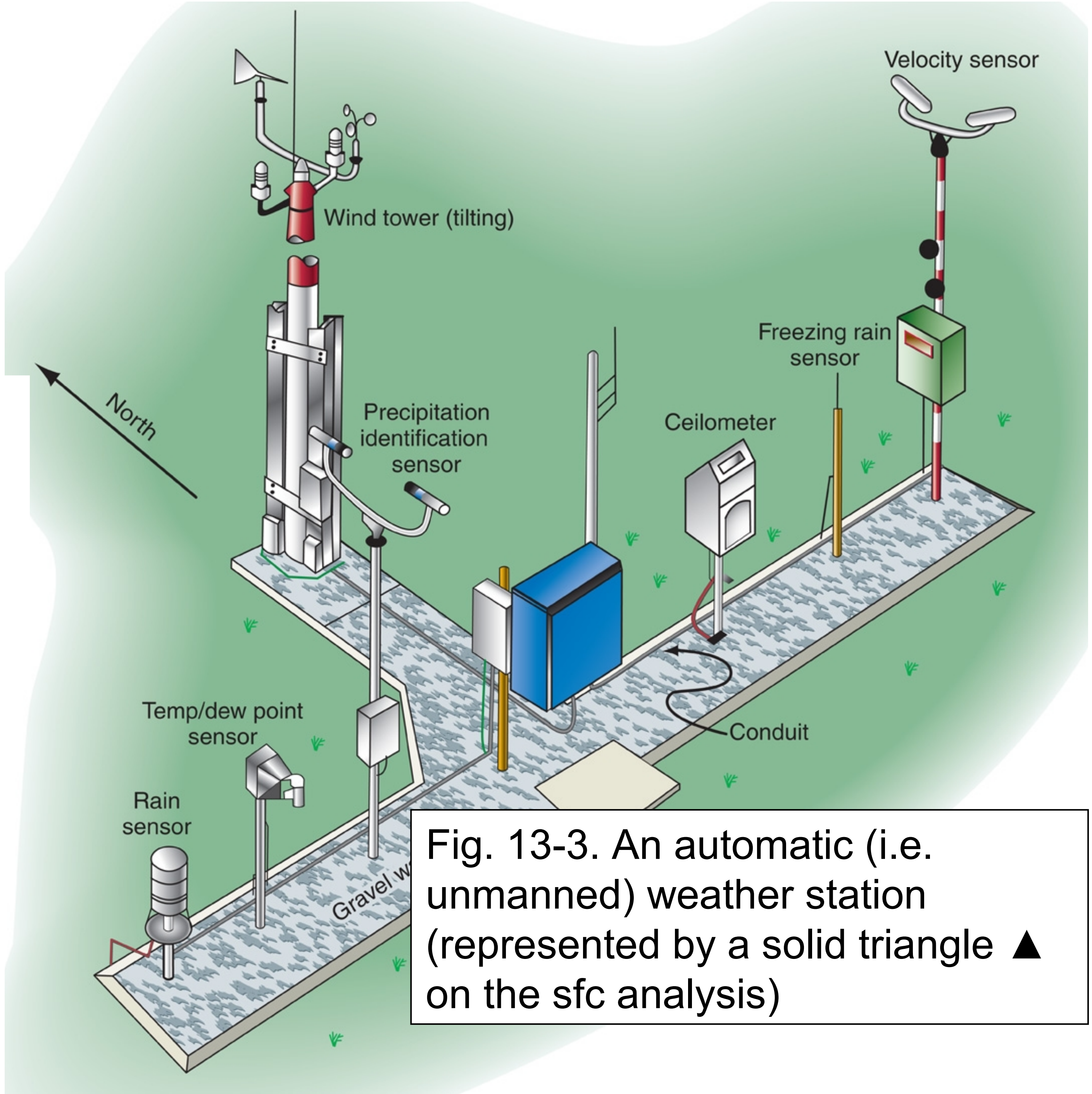


Fig. 13-3. An automatic (i.e. unmanned) weather station (represented by a solid triangle ▲ on the sfc analysis)

Analysis Phase

• quality control… criteria of physical acceptability (eg. no negative pressures) and plausibility relative to climate

• interpolation onto a regular “grid” of points

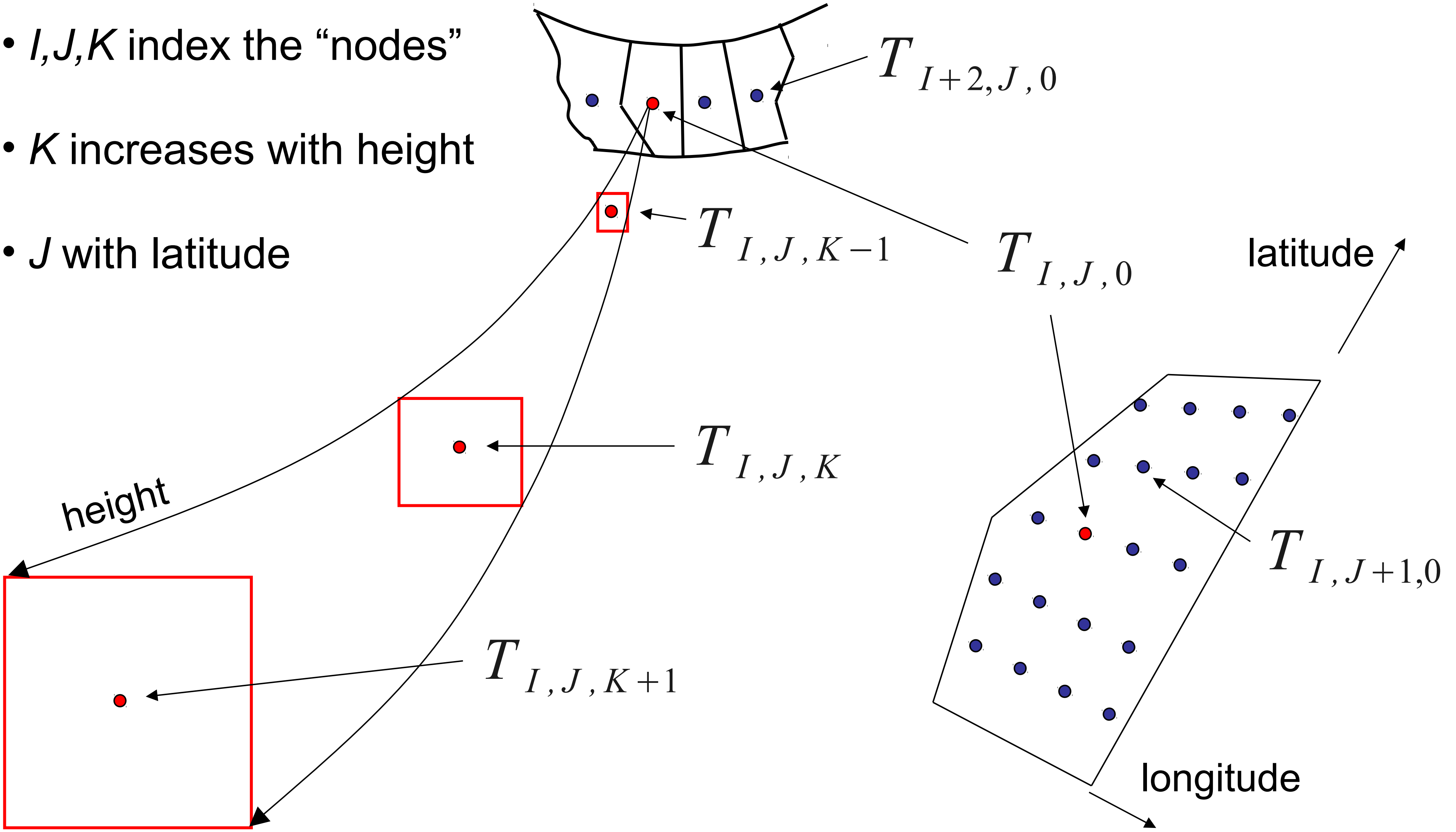
• numerical analysis: adjustment to form fields that are consistent with allowable physics (eg. winds must be such that total mass of air is conserved) and consistent with the numerical model being used

• eg. initial data must not contain features the model is unable to resolve, eg. reduced winds in a small valley not “visible” in model’s terrain) – else “model will adjust to the mismatch” and “contaminate the forecast” (p421)

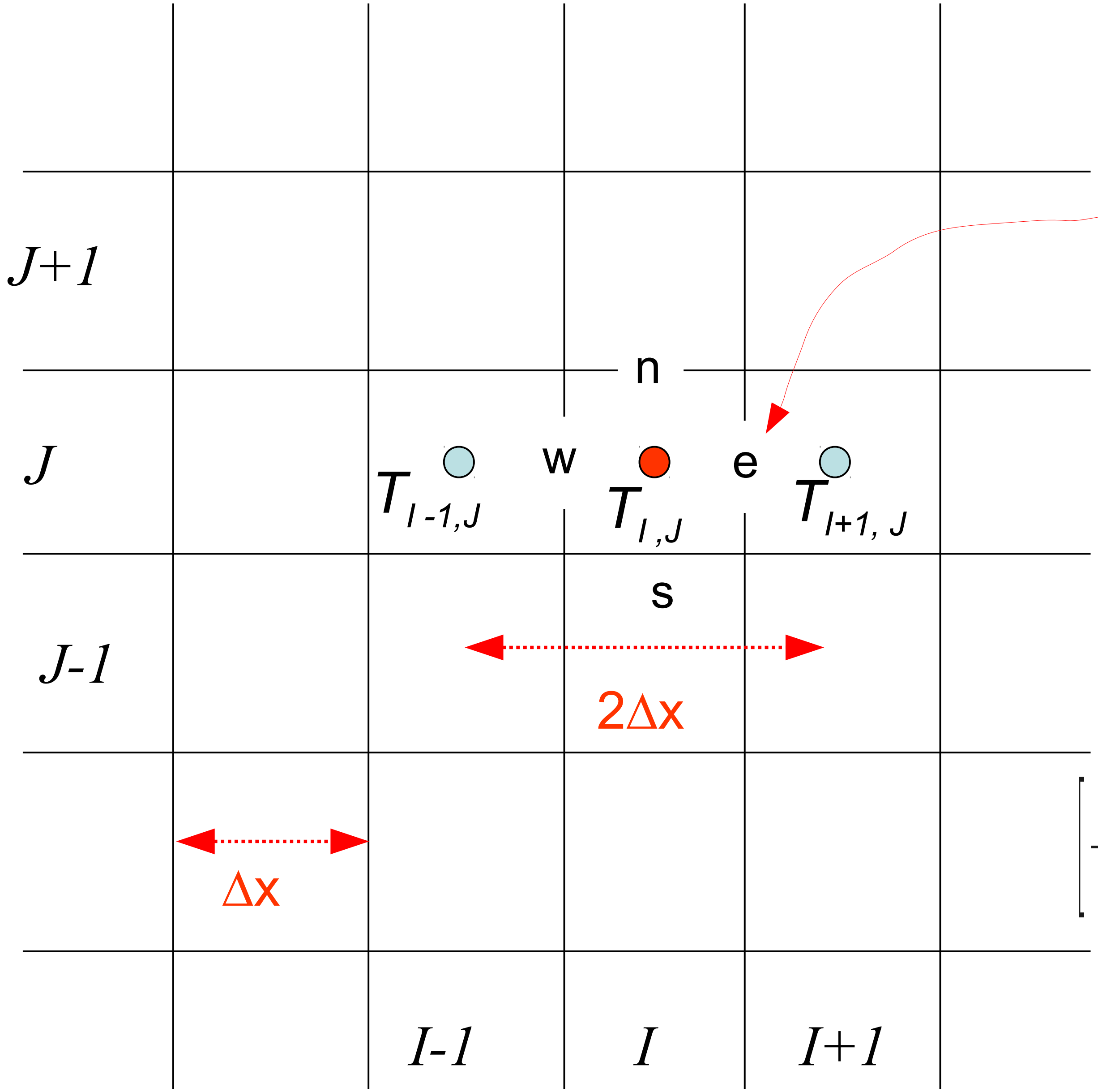
• the “adjustment” blends the observations for the initial time t_0 with a 6 hour forecast (that had been initialized at t_0-6) that is valid at t_0

Numerical Weather Prediction – variables stored on a “grid**”

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



Data on a grid (shown in 2-d), example of "interpolation", and finite-difference representation of a gradient



- values known on grid
- need values on "faces"
- e.g.

$$T_e = \frac{T_{I,J} + T_{I+1,J}}{2}$$

- also need derivatives (gradients), such as

$$\left[\frac{\Delta T}{\Delta x}\right]_{I,J} = \frac{T_{I+1,J} - T_{I-1,J}}{2\ \Delta x}$$

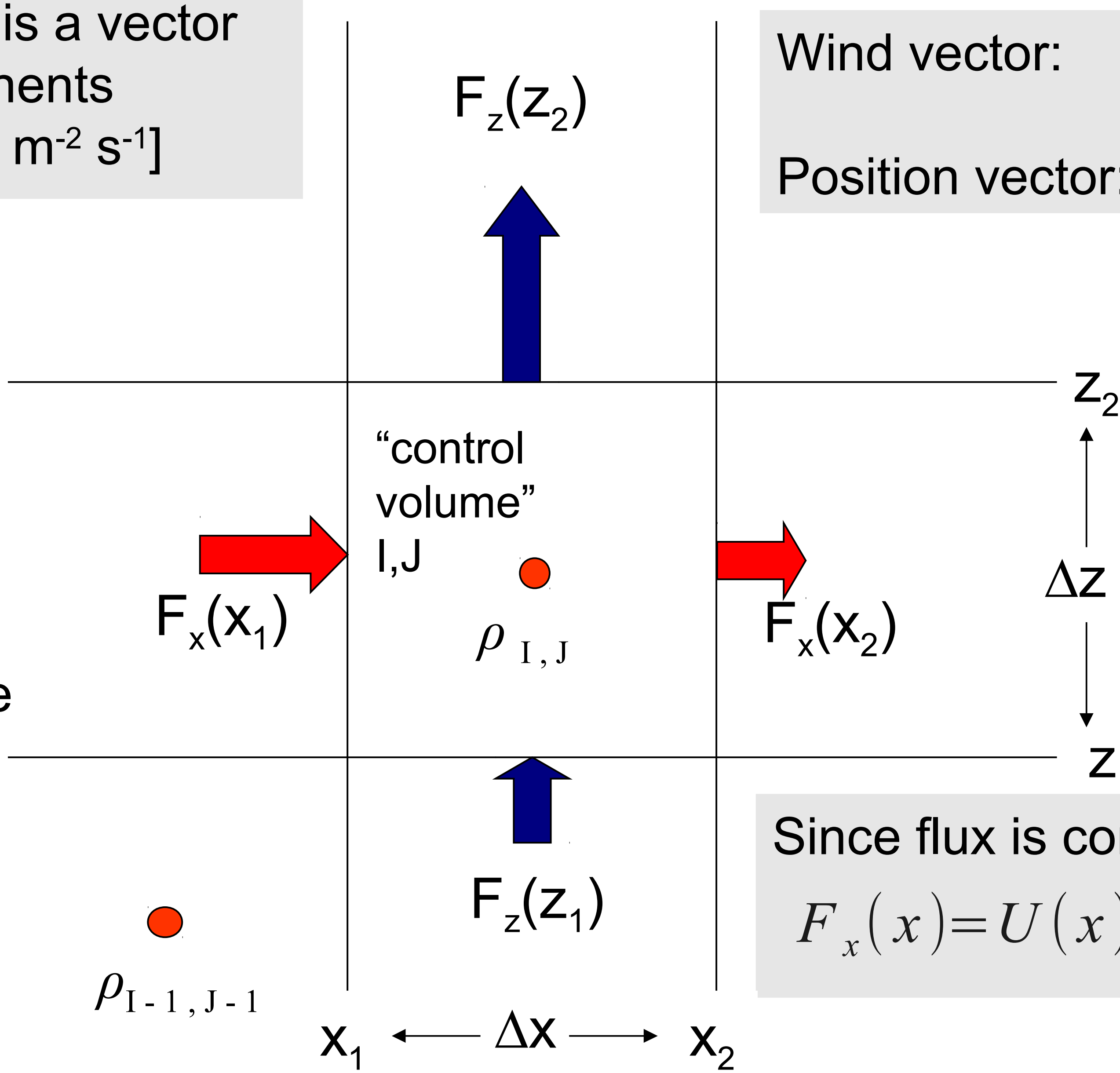
An equation to express conservation of air mass on the grid

"Flux" of air is a vector with components F_{x}, F_{y}, F_{z} [kg m^{-2} s^{-1}]

Wind vector: $\mathbf{V} = (U, V, W)$

Position vector: $\mathbf{x} = (x, y, z)$

- multiply F by face area to get mass of air crossing face per unit of time



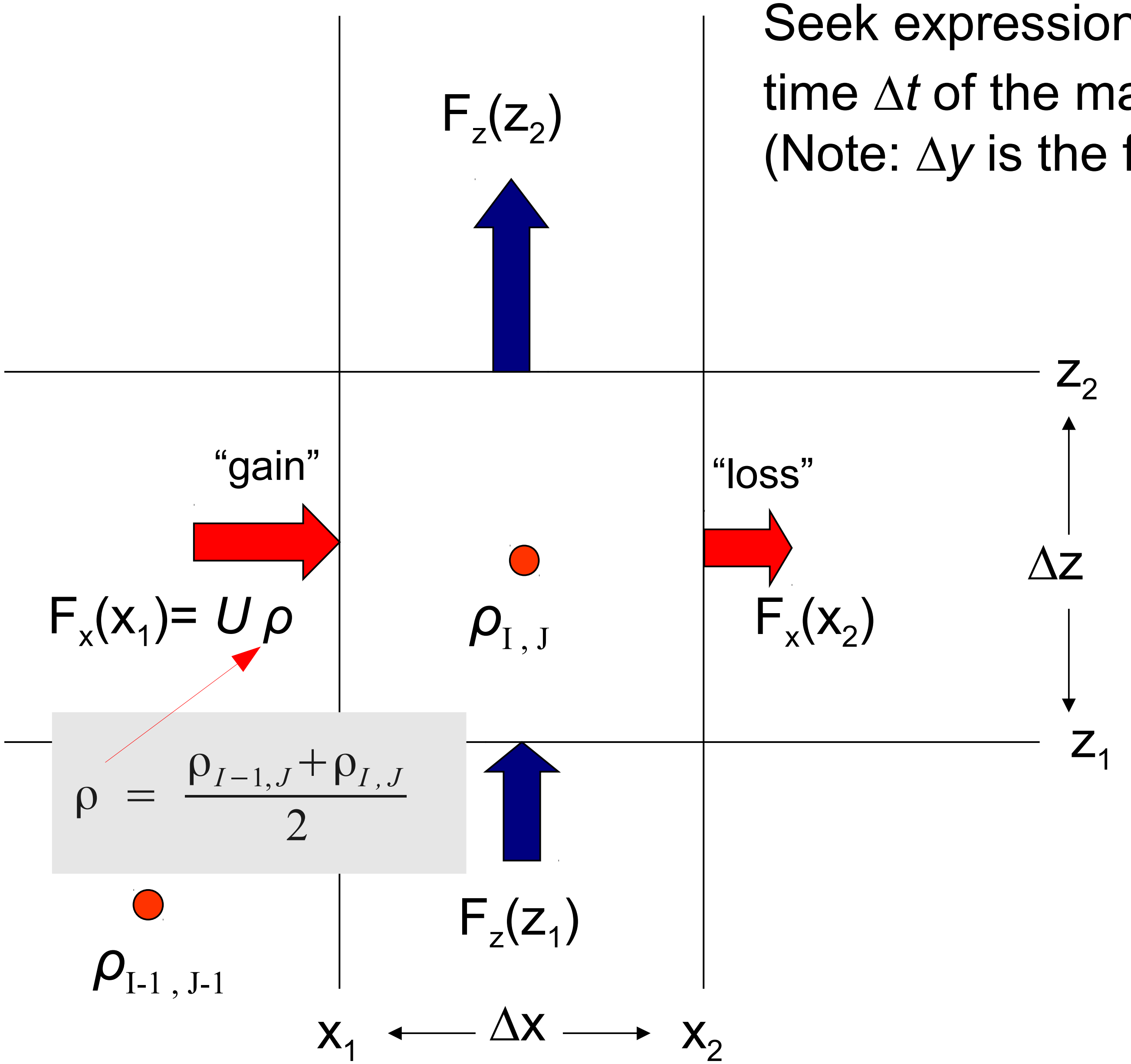
Since flux is convective,

$$F_x(x) = U(x)\ \rho(x)$$

As air cannot be created or dstroyed, the total air content of cell *I,J* can only change if there is a net flux (i.e. net transport) of air across its (imaginary) "cell faces"

Equation to express conservation of air mass in cell labelled *I,J*

Seek expression for the change $\Delta\rho_{I,J}$ over time Δt of the mass [kg] of air in box *I,J* . (Note: Δy is the face length along *y*)



Thus need to interpolate values of *U* and ρ from nodes onto "control volume faces"

Doing so links $\rho_{I,J}$ to $\rho_{I+1,J}$ *and* $\rho_{I-1,J}$ *and* $\rho_{I,J+1}$ *and* $\rho_{I,J-1}$

Neighbouring values are "convectively coupled"

On the next page we add up all the gains and subtract the losses of mass thru faces...

Equation to express conservation of air mass in cell labelled *I,J*

density change over time step Δt

volume of cell

$$\Delta x \, \Delta y \, \Delta z \, \Delta \rho_{I,J} = \Delta t \, \Delta z \, \Delta y \left[F_x(x_1) - F_x(x_2) \right]$$

$$+ \Delta t \, \Delta z \, \Delta x \left[F_y(y_1) - F_y(y_2) \right]$$

$$+ \Delta t \, \Delta x \, \Delta y \left[F_z(z_1) - F_z(z_2) \right]$$

area of top/bottom faces of cell

rate of transport of mass into the cell (per unit face area per unit time) through the bottom face. By interpolation, these “fluxes” can be expressed in terms of the values of velocity and density at the grid points

Numerical integration (prediction phase)

Governing equations have form (eg.)

$$\left(\frac{\Delta T}{\Delta t}\right)^{n}_{I,J,K} = -U^{n}_{I,J,K}\left(\frac{\Delta T}{\Delta x}\right)^{n}_{I,J,K} - V^{n}_{I,J,K}\left(\frac{\Delta T}{\Delta y}\right)^{n}_{I,J,K} + \ldots$$

(terms shown on r.h.s. are advection of heat along the x- and *y*-axes).

Upon re-arrangement one has a formula to advance the temperature at gridpoint (*I,J,K*) over time interval Δt (7.5-min for GEM in regional configuration) from time "*n*" to time "*n+1*"

$$T^{n+1}_{I,J,K} = T^{n}_{I,J,K} + \left(\frac{\Delta T}{\Delta t}\right)^{n}_{I,J,K} \Delta t$$

Repeat the process to go from time "n+1" to "n+2"… out to 12, 24, 36, 48 hours (or longer). End result: forecast fields of *U,V,W,T,P, ρ, Q* (humidity) on the grid

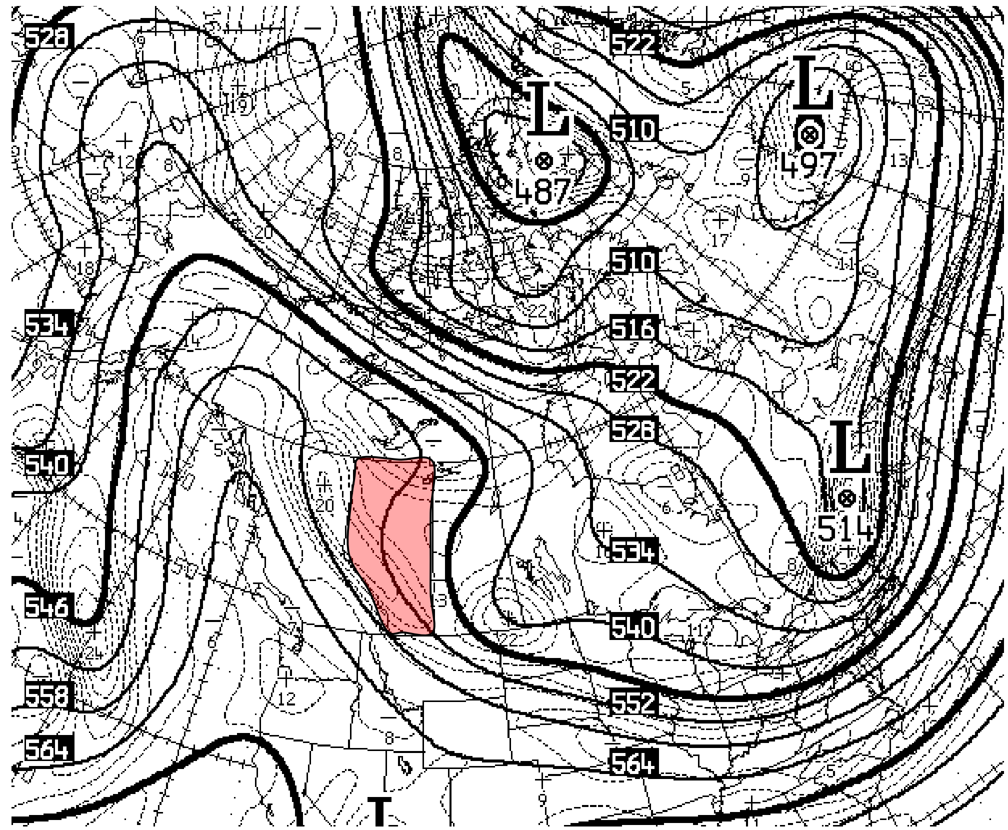
Post-processing phase

- Forecast products usually involve subjective human involvement. Forecaster compares models, knows which aspects of which models have proven reliable

ALERT: Received the following bulletin at Mon Dec 02 08:04:08 UTC.
MAIN WX DISCUSSION, UPPER LEVEL PATTERN

WHILE OVER W CST THE L/W UPPER RIDGE WILL PERSIST, CONDITIONS WILL BE QUITE ACTIVE IN THE VAST CYCLONIC CIRCULATION COVERING ALMOST ENTIRE CANADA AND ARCTIC... HOWEVER DESPITE THIS HIGHLY CHANGING UPPER LEVEL PATTERN, MODELS ARE IN QUITE GOOD AGREEMENT FOR THE UPPER LEVEL PATTERN EVOLUTION NEXT 48 HRS. SINCE REGGEM HAS VERIFIED THE BEST PAST RUN AND IS VERY CONSISTENT, WE ACCEPT ITS SCENARIO.

- produce and distribute maps for mandatory levels, to convey model output to forecasters



may use rules of thumb and/or supplementary statistical algorithms to forecast weather elements, eg. tomorrow’s max or visibility for an airport

EC's Global Environmental Multiscale (GEM) model, in its regional configuration – 15 km grid spacing over N. America, time step 7.5 min

Model Output Statistics (MOS)

Forecasting algorithm that employs an established (historical) statistical correlation between:

- past observed values of weather variables (eg. visibility V), and

- corresponding forecast values of a set of "relevant" variables from NWP model (eg. local 500 mb height H_{500}, wind speed and direction at 850 mb, U_{850}, θ_{850}, etc.)

- of form $V = V(H_{500}, U_{850}, \theta_{850}, \ldots)$

- used predictively with machine forecasts to predict future weather

- this partly "corrects" flaws in NWP model. But MOS correlations must be re-calculated ("re-trained") for each revision of NWP model

Medium-range forecasting

- Numerical forecast for ranges of order 3-15 days
- not much skill beyond one week
- to some extent this limit to useful forecast lead time arises from the extreme sensitivity of the governing equations to initial conditions – forecast is vulnerable to growth of errors in initial state
- increasingly common to perform “ensemble forecast” (multiple model runs starting from slightly different initial conditions that attempt to mimic possible errors in the initial data). Variability of the forecast amongst ensemble-members implies greater uncertainty

Long-range seasonal anomaly forecasting

- both statistical and dynamical techniques are used
- where numerical models involved, must be coupled land-atmosphere-ocean
- at present, low skill

Ensemble forecasting

- multiple model runs starting from slightly different initial conditions – mimic possible errors in the initial data

- variability of the forecast amongst ensemble-members implies greater uncertainty

Attributes of NWP models

- domain & boundary conditions (eg. if global, no lateral boundaries). Longer forecast range demands more remote boundaries

- spatial and temporal resolution

} trade-offs in speed vs. detail

- grid or "spectral" (p446) representation?

- model "dynamics" (approximations in the equations, eg. hydrostatic?; choice of dependent variables, eg. velocity or vorticity?...)

Sometimes a high resolution local model is "nested" within the larger domain of a lower resolution model that furnishes it the needed boundary conditions

Even in its configuration for the "regional run" (4 x daily) Canada's GEM has global domain

Attributes of NWP models

• model "physics" (which includes "parameterizations" of effects of unresolved scales of motion – "subscale processes"):

  • radiation as function of model's diagnosed cloud and possibly other resolved properties such as humidity, CO_2 concentration…

  • convection (deep & shallow), clouds (stratiform & cumuliform) & precip

  • surface exchange (momentum, heat, vapour, CO_2…) based on surface state, analyzed or forecast

  • drag on unresolved terrain features

Compromising limitations of numerical weather forecasting

- extreme sensitivity to initial data (growth of initial errors)

- data-sparse regions

- inability to represent all scales of motion, from the planetary down to the scale of a cloud droplet
  - at present, grid-spacing order 10 km in horiz… thus for example no possibility to model cumulus… effects of cumulus must be "parametrized" (eg. diagnose cloud base and cloud top height from model's temperature and humidity profiles: re-mix heat and vapour uniformly in that layer)
  - some processes entirely missing
  - others (eg. land-atmosphere exchange, drag on small hills) oversimplified/poorly represented

Forecast Assessment

Quality versus Value

skill accuracy

- forecast method is considered “skillful” if it provides (in a statistical sense) greater accuracy than forecasts based on persistence and climatology

- forecasting extremes: valuable when right, penalizing when wrong – statistically, forecasters are more likely to be correct if they forecast near-average conditions

- types of f/c include qualitative (categorical), quantitative, probability f/c

- many criteria exist for accuracy of f/c, eg. mean absolute error (MAE) average *magnitude* of difference between f/c and actuality

The "omega-block" (or "omega high")

- tends to persist
- predictable weather
- useful hint to forecaster

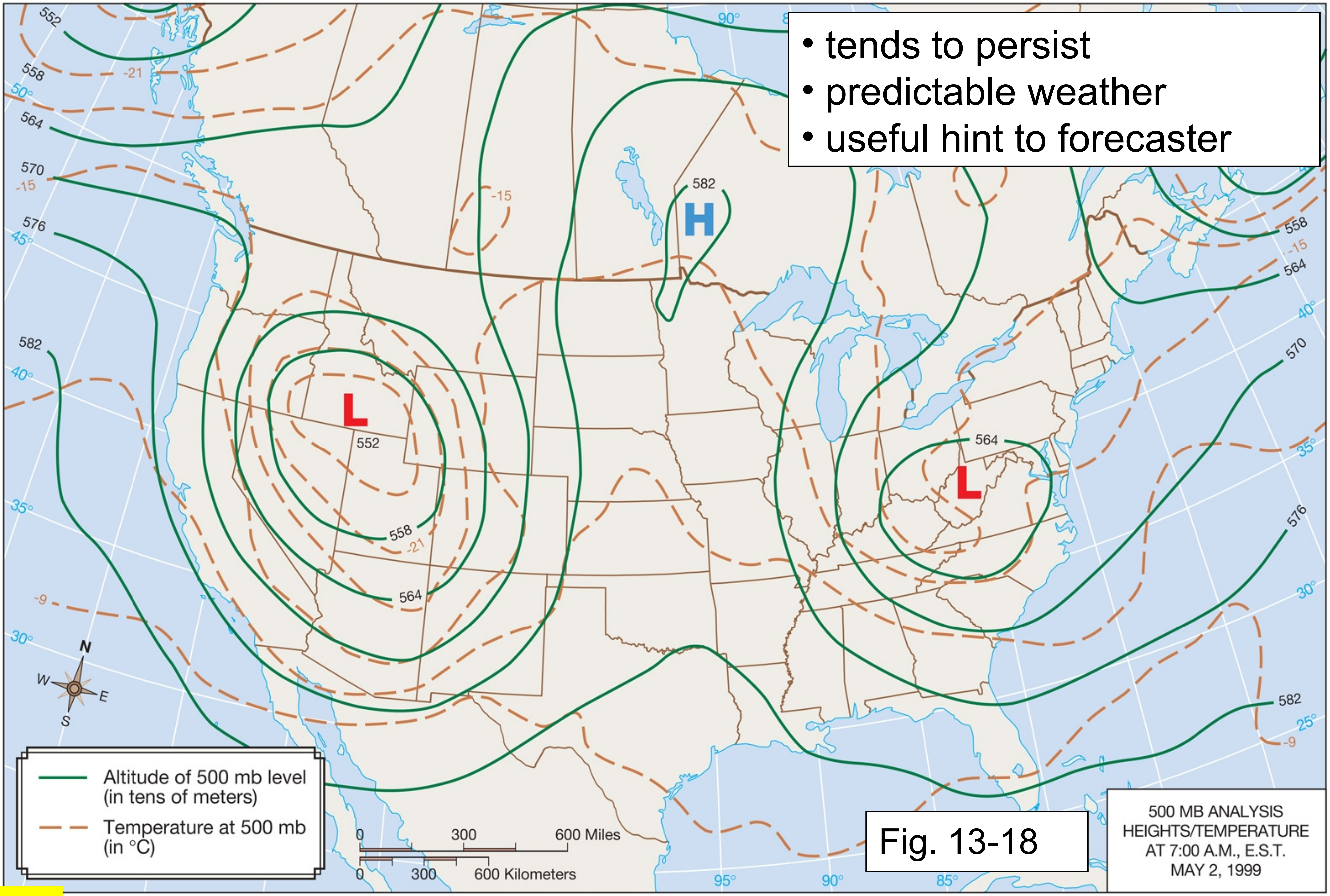


Fig. 13-18

Weather in relation to Operation Uranus – Soviet encirclement of besieging German 6th Army at Stalingrad; 19 Nov., 1942

From Ch15 of A. Beevor's *"Stalingrad. The Fateful Siege: 1942-1943"*

"All through the night, Soviet sappers in white camouflage suits had been crawling forward in the snow, lifting anti-tank mines… One Soviet general said that the freezing white mist was 'as thick as milk'… Front headquarters considered a further postponement, due to the bad visibility, but decided against it…

'Once again, the Russians have made masterly use of the bad weather,' wrote (General von) Richthofen

During the afternoon of 19 November, the Soviet tanks advanced southwards in columns through the freezing mist… it was Butkov's 1st Tank Corps which finally encountered the gravely weakened 48th Panzer Corps. The German tanks still suffered from electrical problems, and their narrow tracks slid around on the black ice. The fighting in the gathering dark was chaotic. The usual German advantages of tactical skill and coordination were entirely lost."