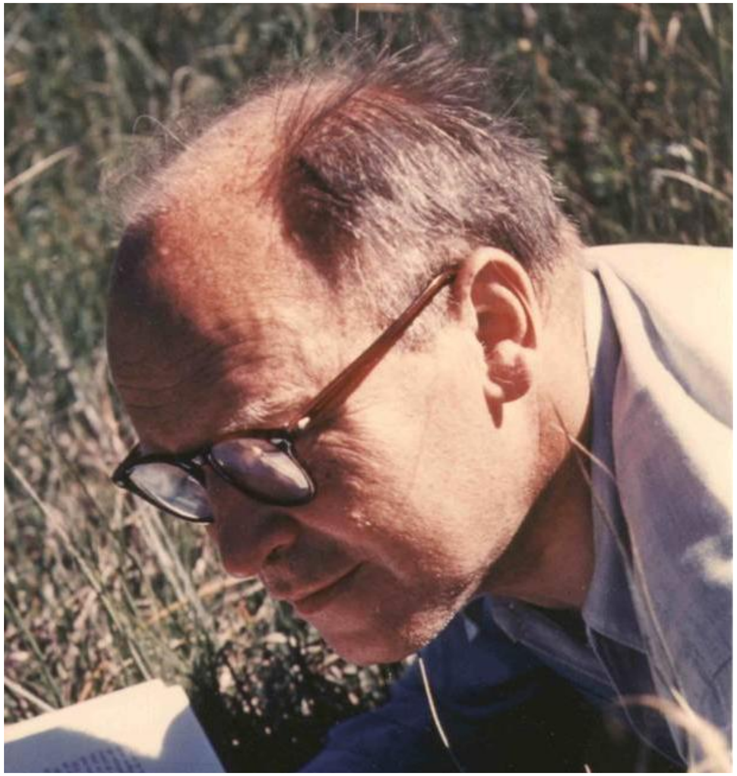
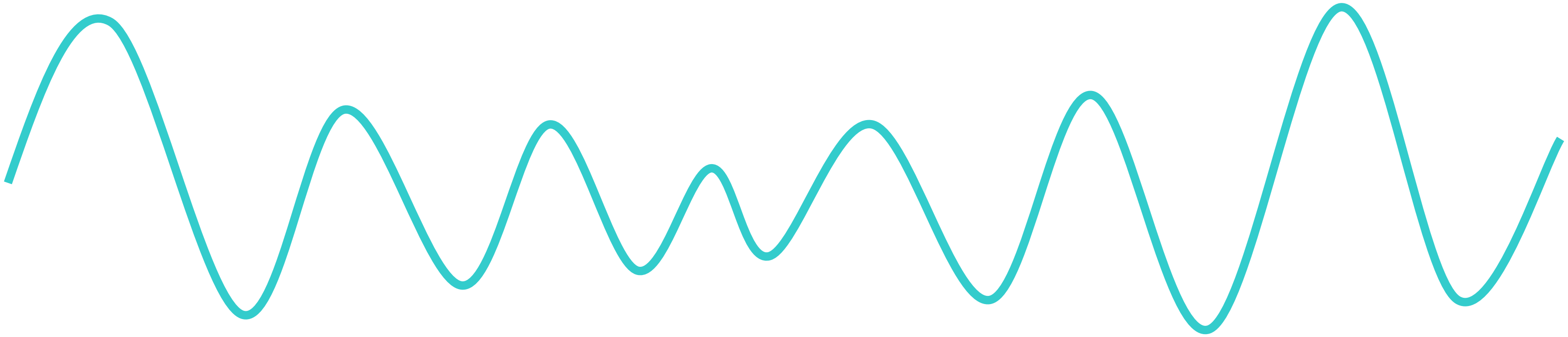
## Dynamic meteorology without tears

# Part VI: Downstream development and “group velocity thinking”

In summer 1944 Carl Gustaf Rossby, then chief meteorological advisor to the US war government, took a vacation in the oceanographic research centre La Jolla in southern California

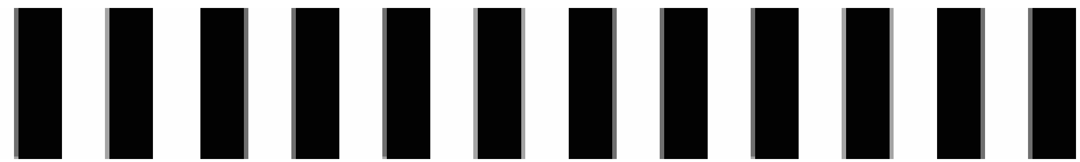
Resting on the beech he could listen to the sound of the incoming waves, their rhythm with a peculiar periodicity, **"The Seventh (or Ninth) Wave"** a consequence of group velocity

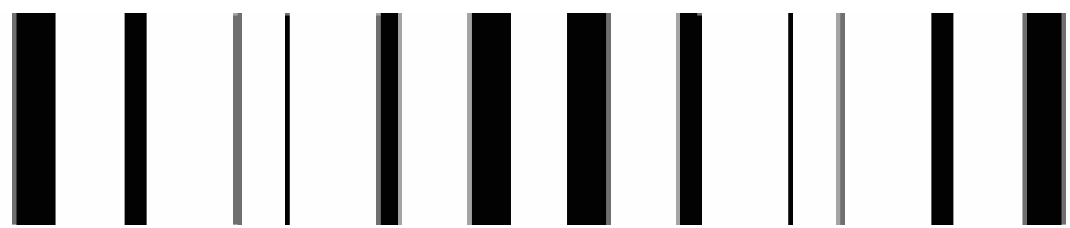




The concept of group velocity can be illustrated by two combs with slightly different spacing between the tags

The phase speeds of the two wave systems (or comb tags!) are different





Their inference pattern moves with a different velocity, **the group velocity** (in this case *slowly* backwards)

# Group velocity in water surface waves

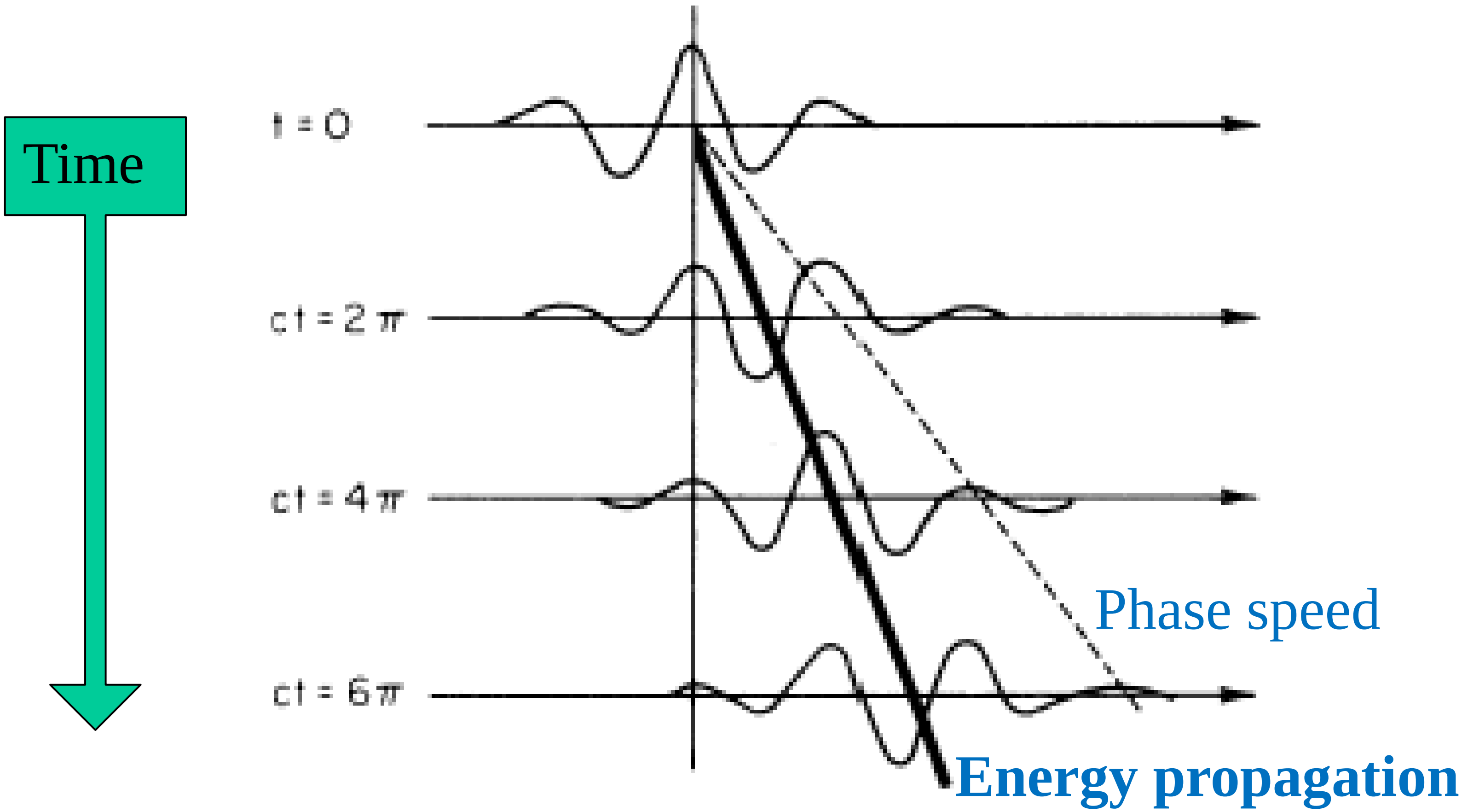



Fig.1 The successive progression of water wave packages. The crest in the centre moves rapidly out, weakens and leaves behind the main energy, into which upstream waves enter and amplify (from Holton, 1992).

Phase speeds ***c*** according to Rossby's wave equation

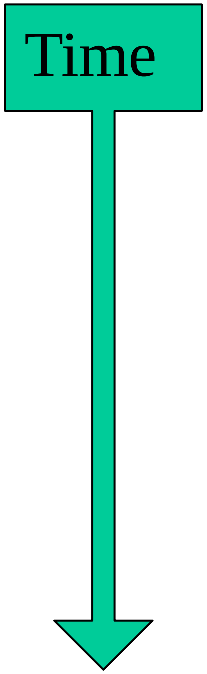
$$c = U - \frac{\beta L^2}{4\pi^2} \approx 10^\circ / day$$

This wave equation is ***dispersive*** and gives rise to "downstream development" by the ***"group velocity"***

$$c_g = U + \frac{\beta L^2}{4\pi^2} \approx 30^\circ / day$$

propagating energy ("influences") rapidly downstream

# Group velocity in the atmosphere



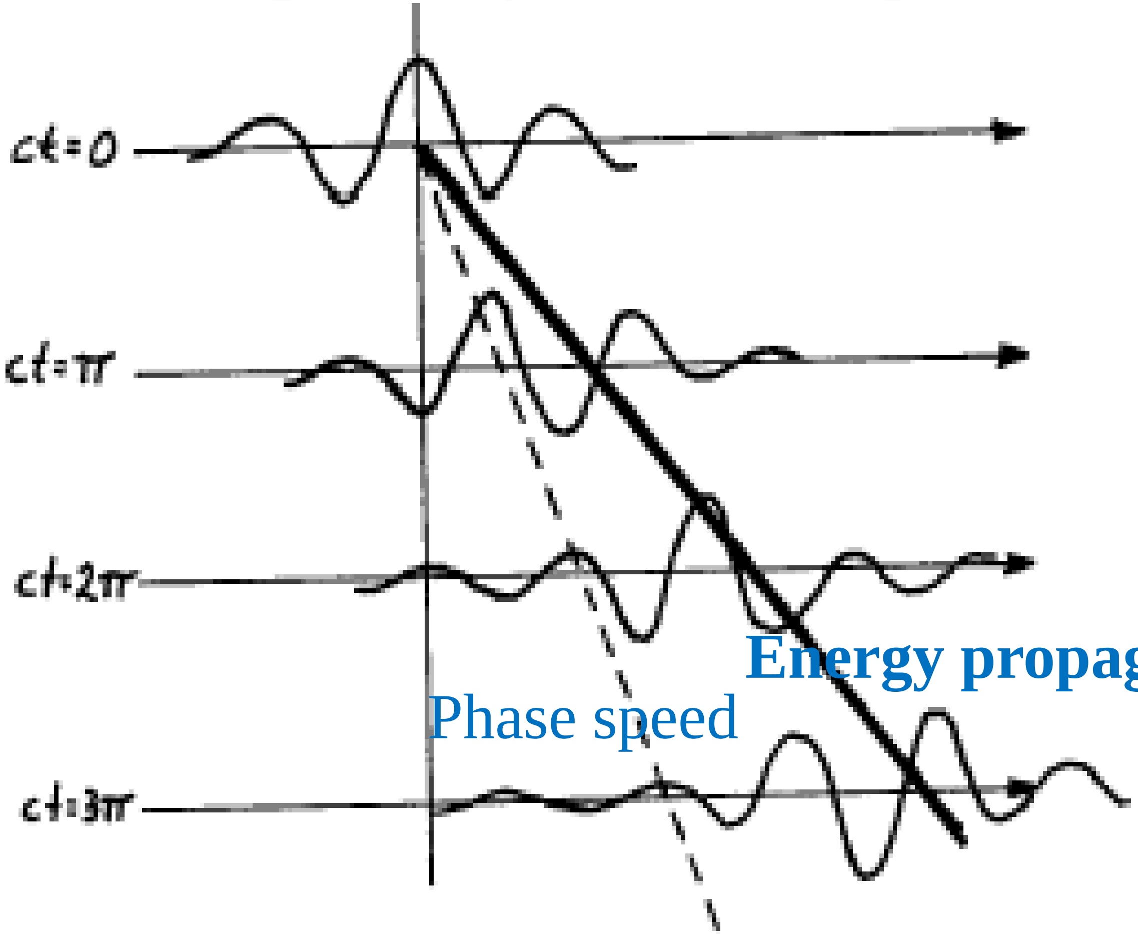




Fig. 2: The corresponding mechanism in the atmosphere: the central wave moves more slowly than the bulk of the energy which propagates downstream amplifying waves on its arrival.

# From an upstream baroclinic development the released kinetic energy is transported, through the upper-tropospheric flow, to the next downstream cyclone

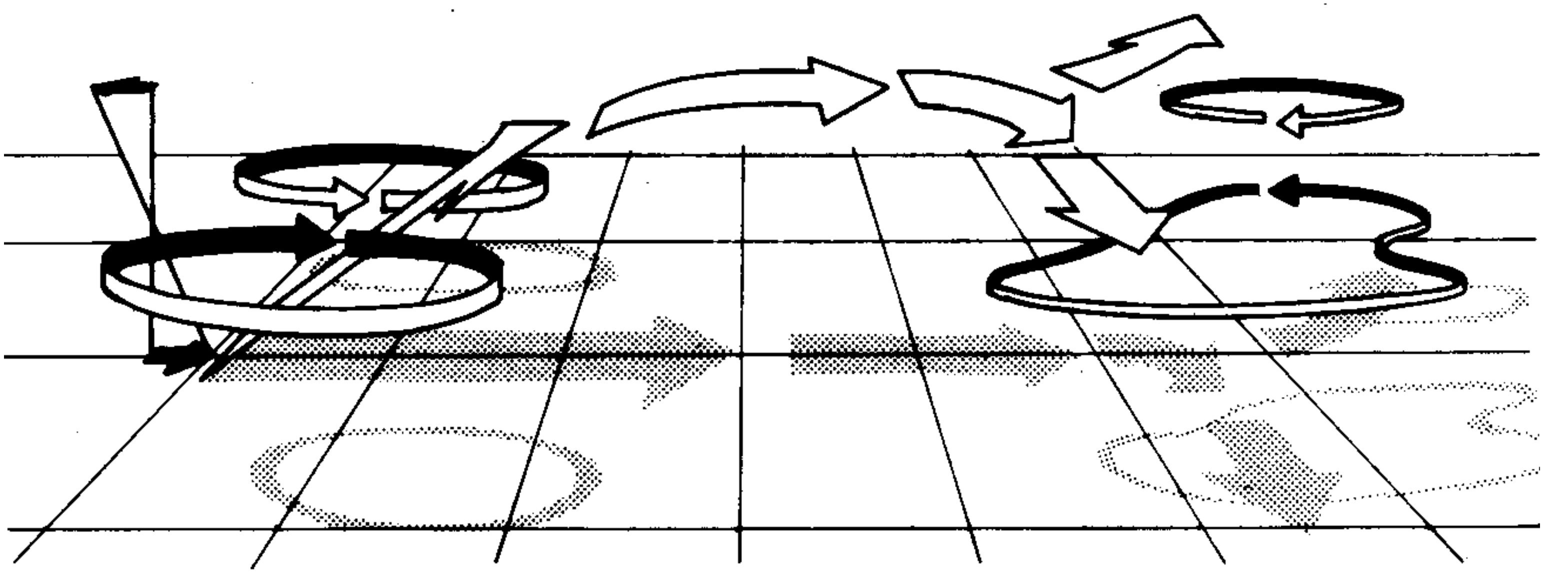
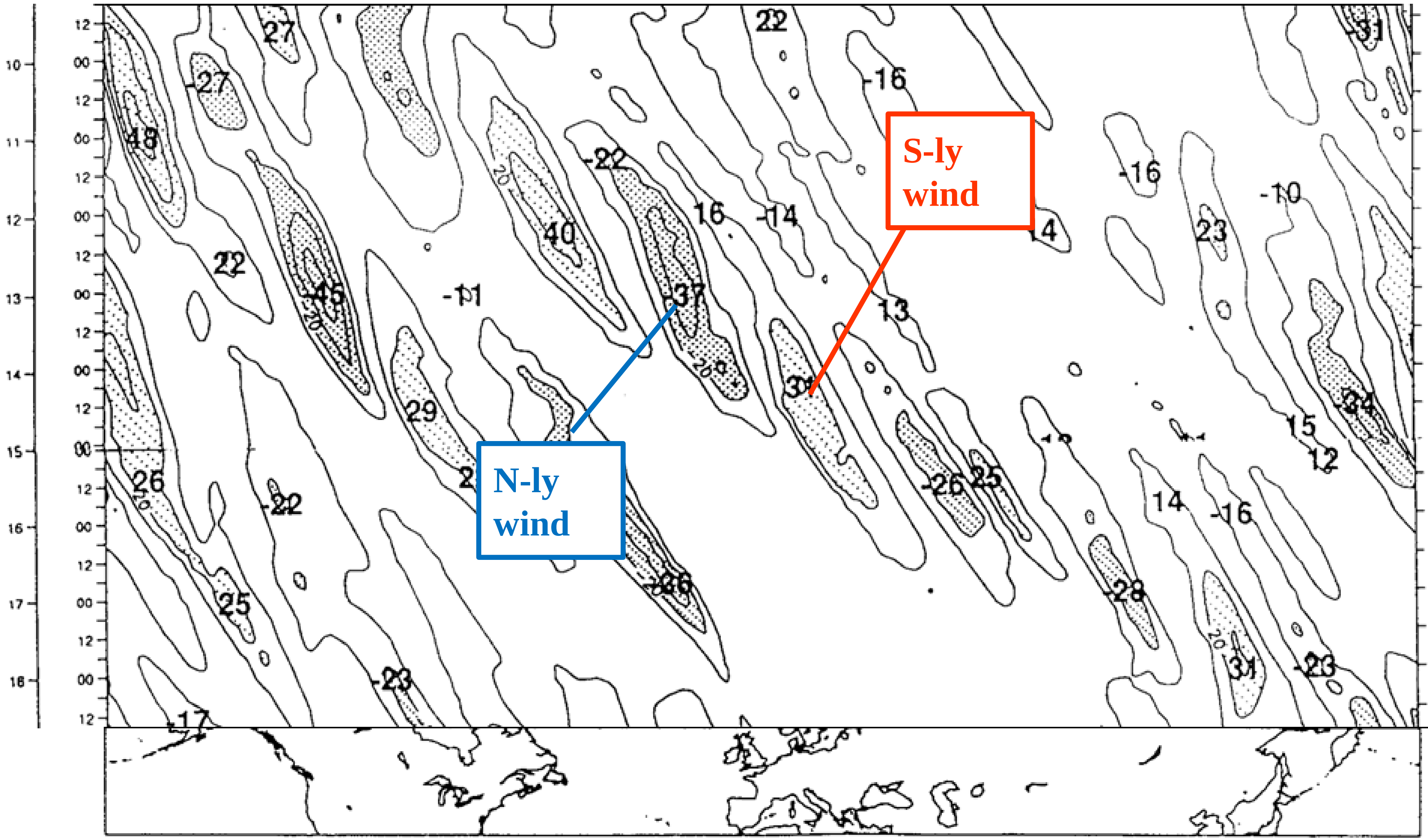


Illustration from Hoskins, James and White (JAS, 1983)

# Trough-ridge (Hovmöller) Diagram

of 250 hPa meridional wind component 10-18 September 1993



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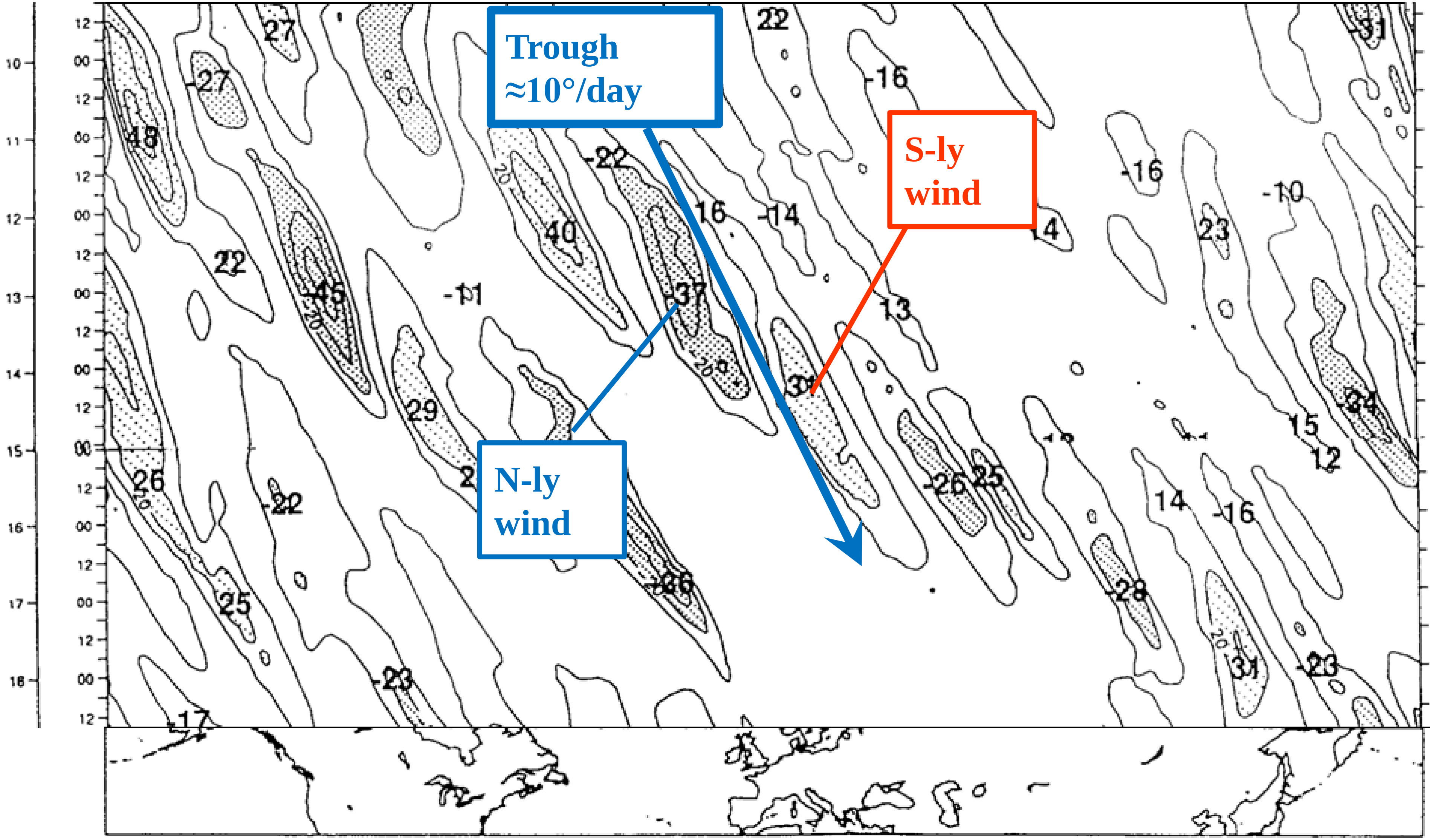

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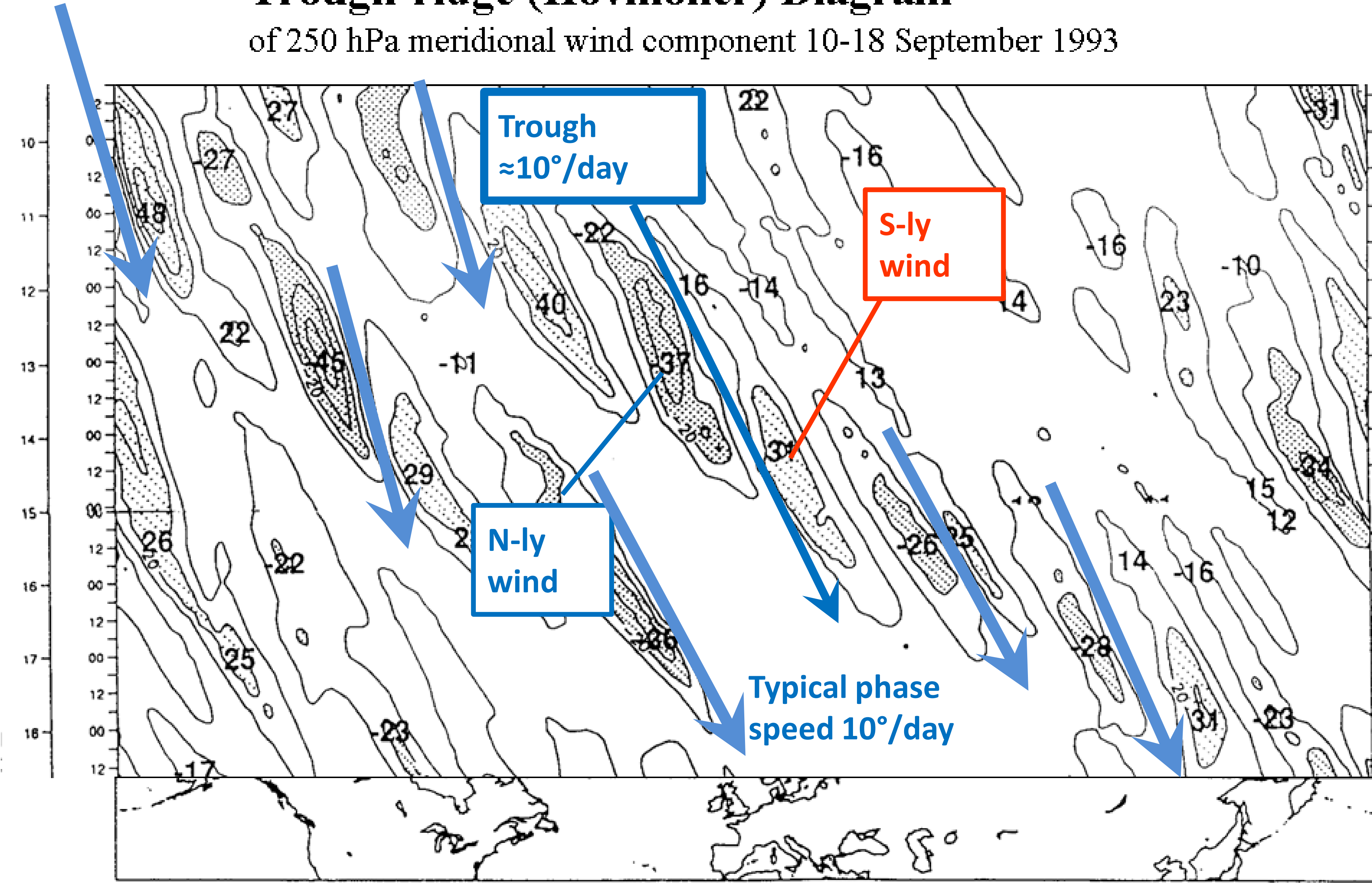

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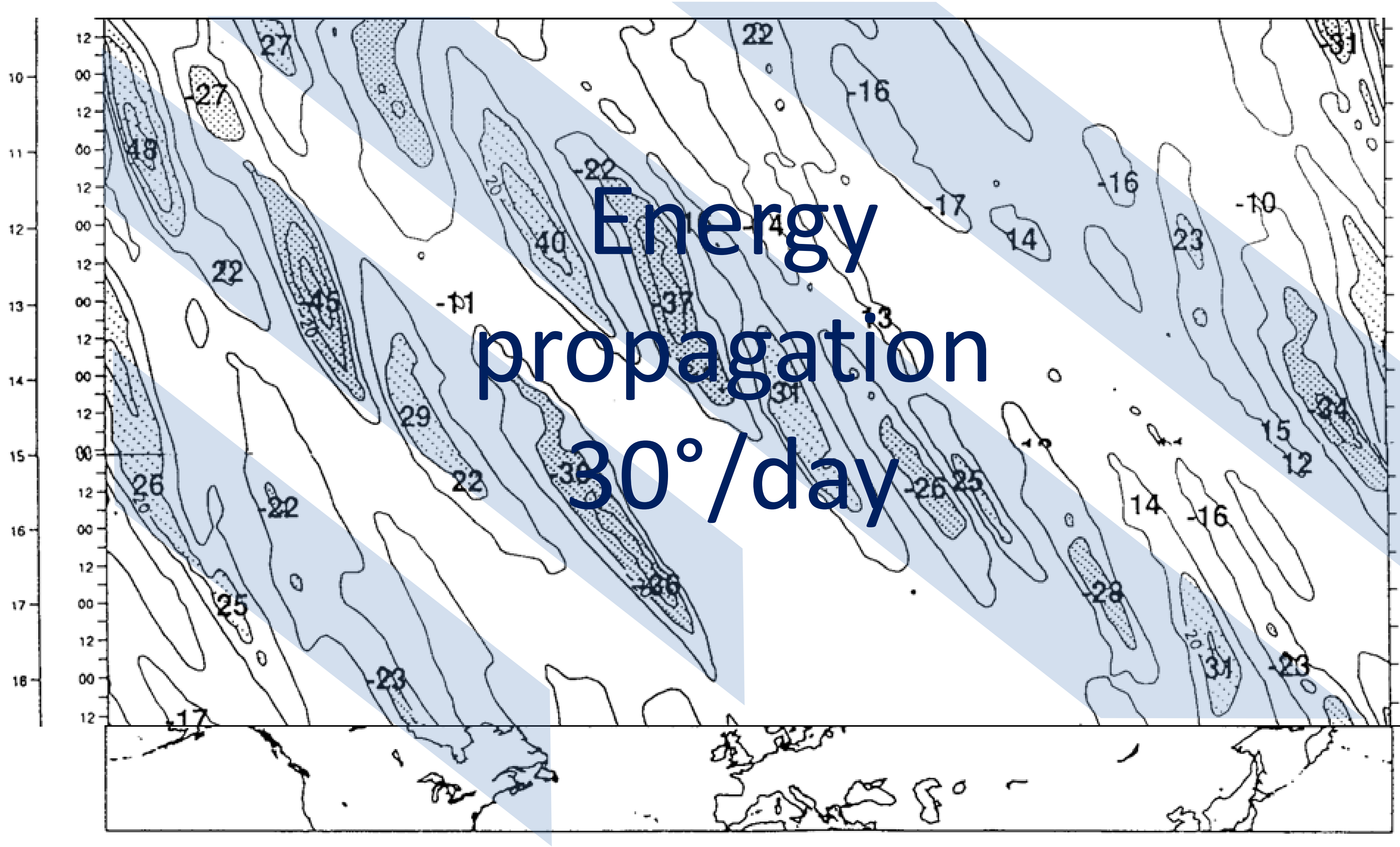
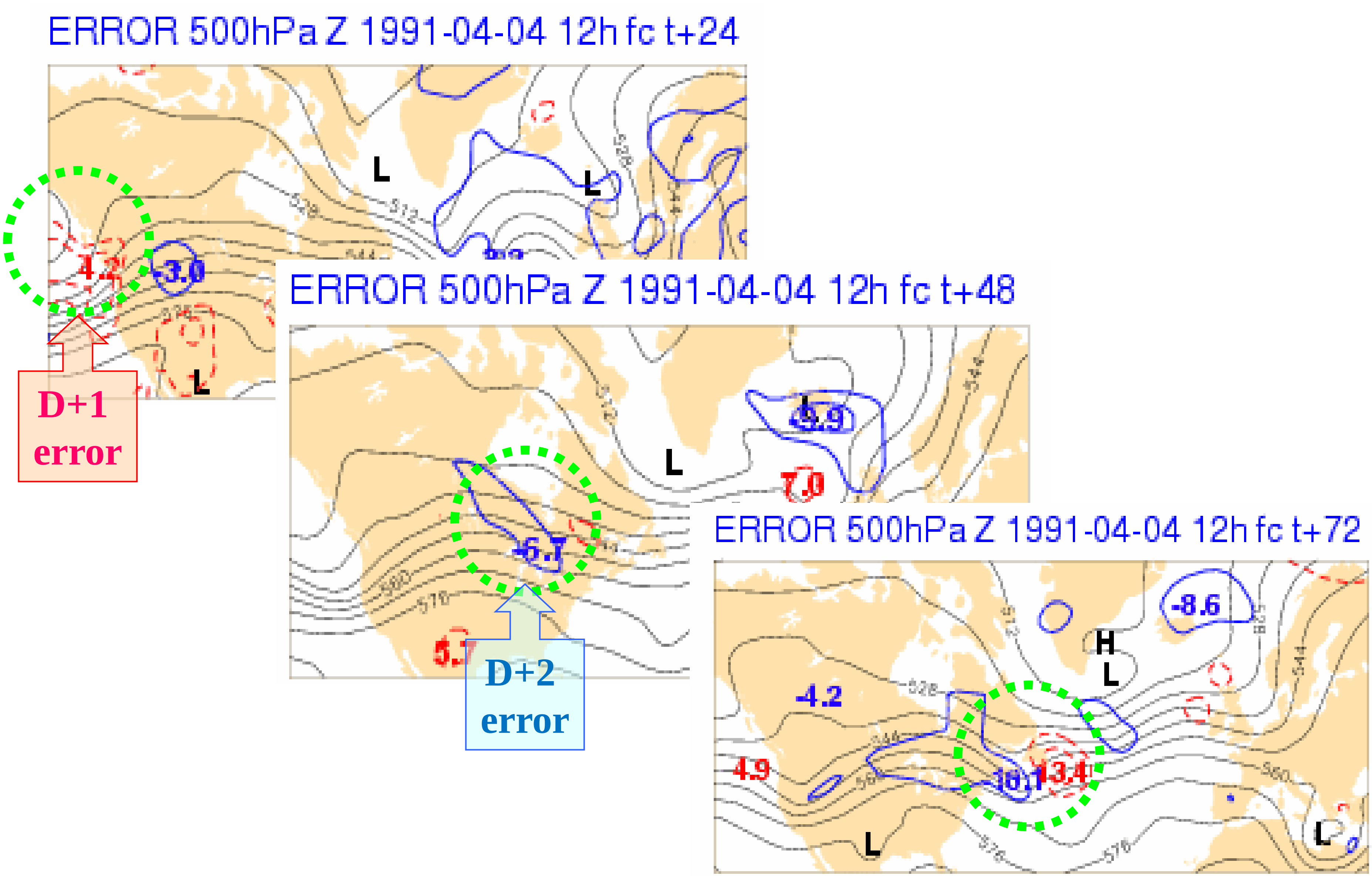


At ECMWF, UKMO and other NWP centres “group velocity thinking” is used to trace the origin of forecast errors (or forecast “jumps”) due to poor initial conditions

# Error tracking from the NE Pacific to Europe in 6 days



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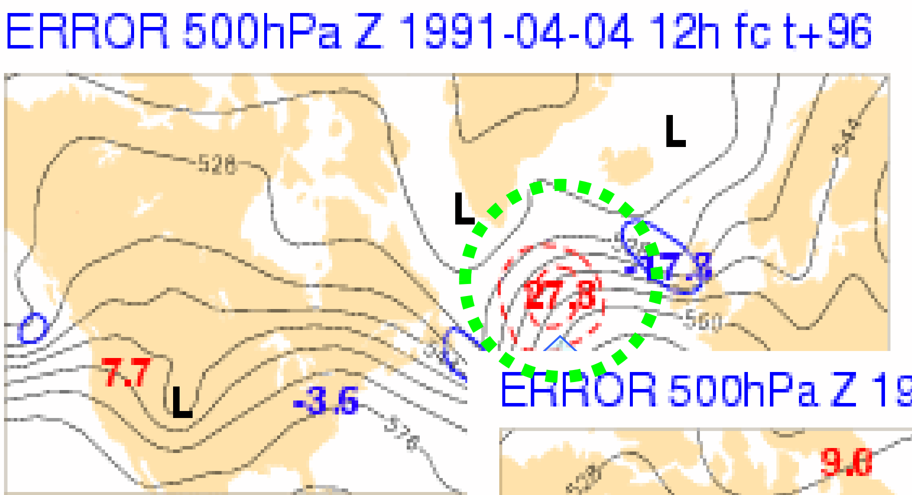
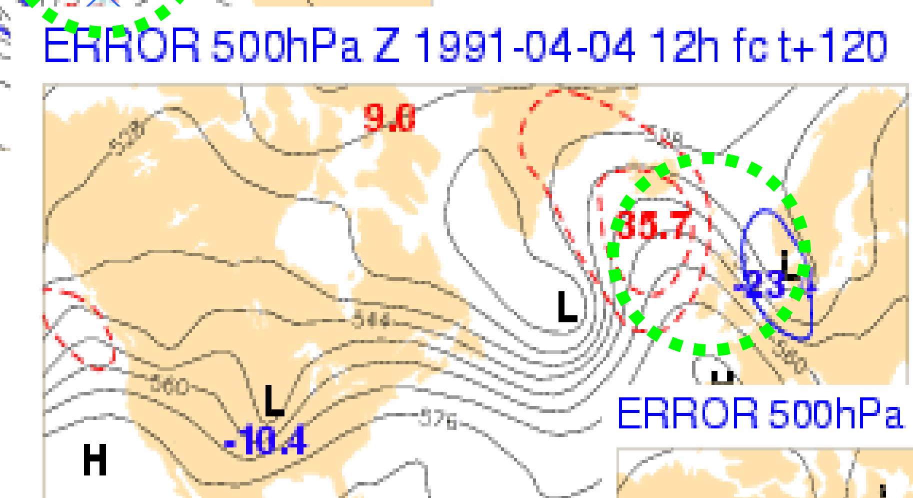
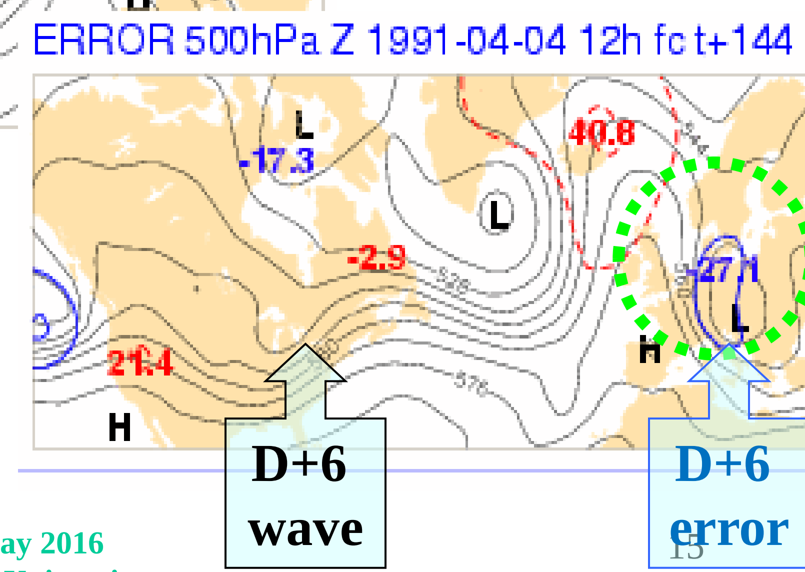
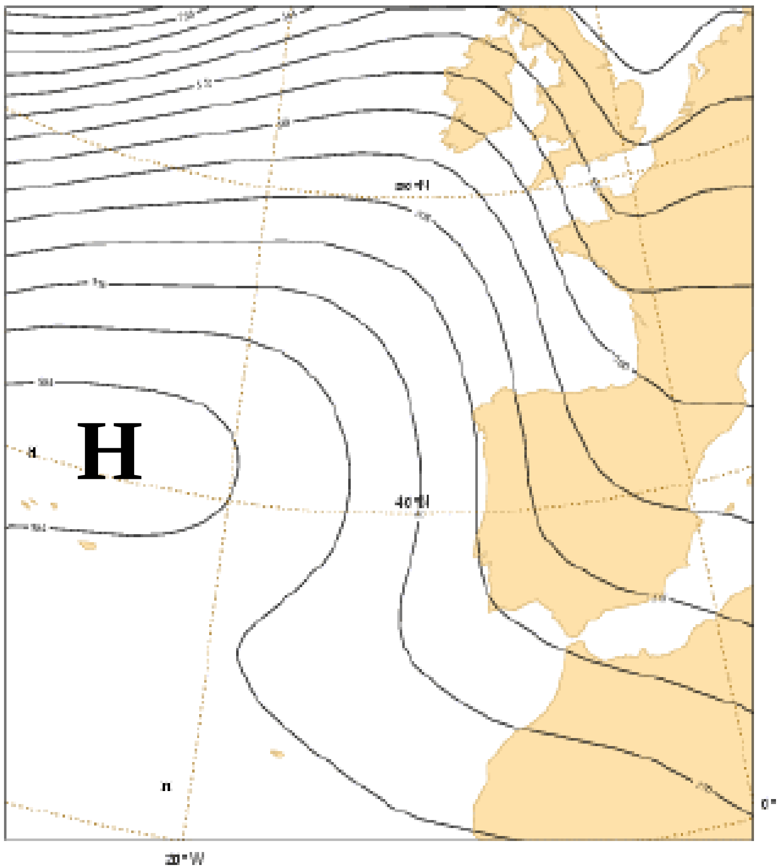


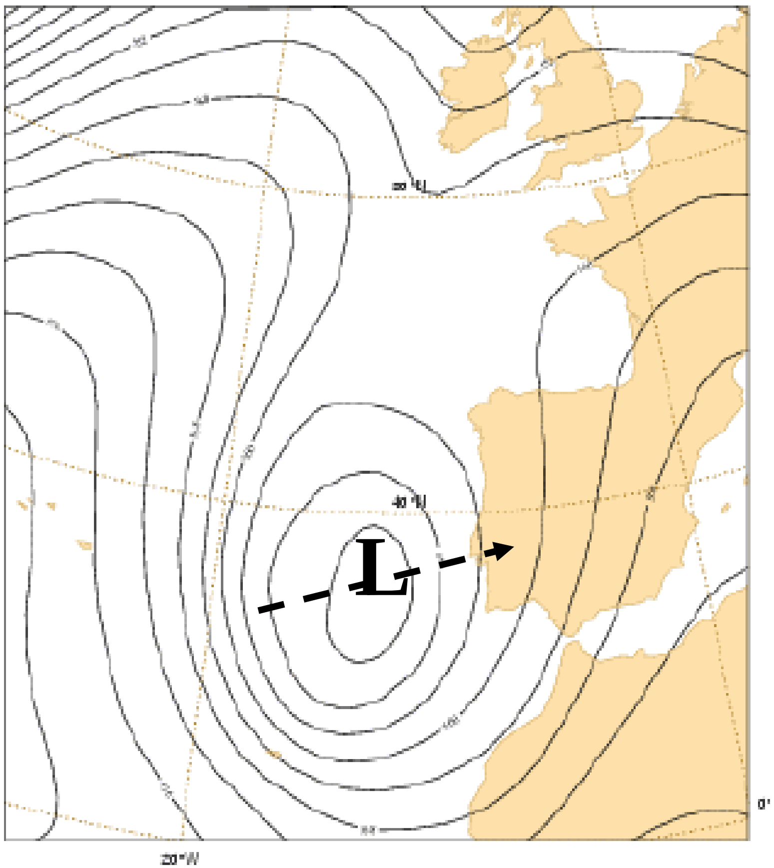



# A “jumpy” forecast of a Spanish cut-off

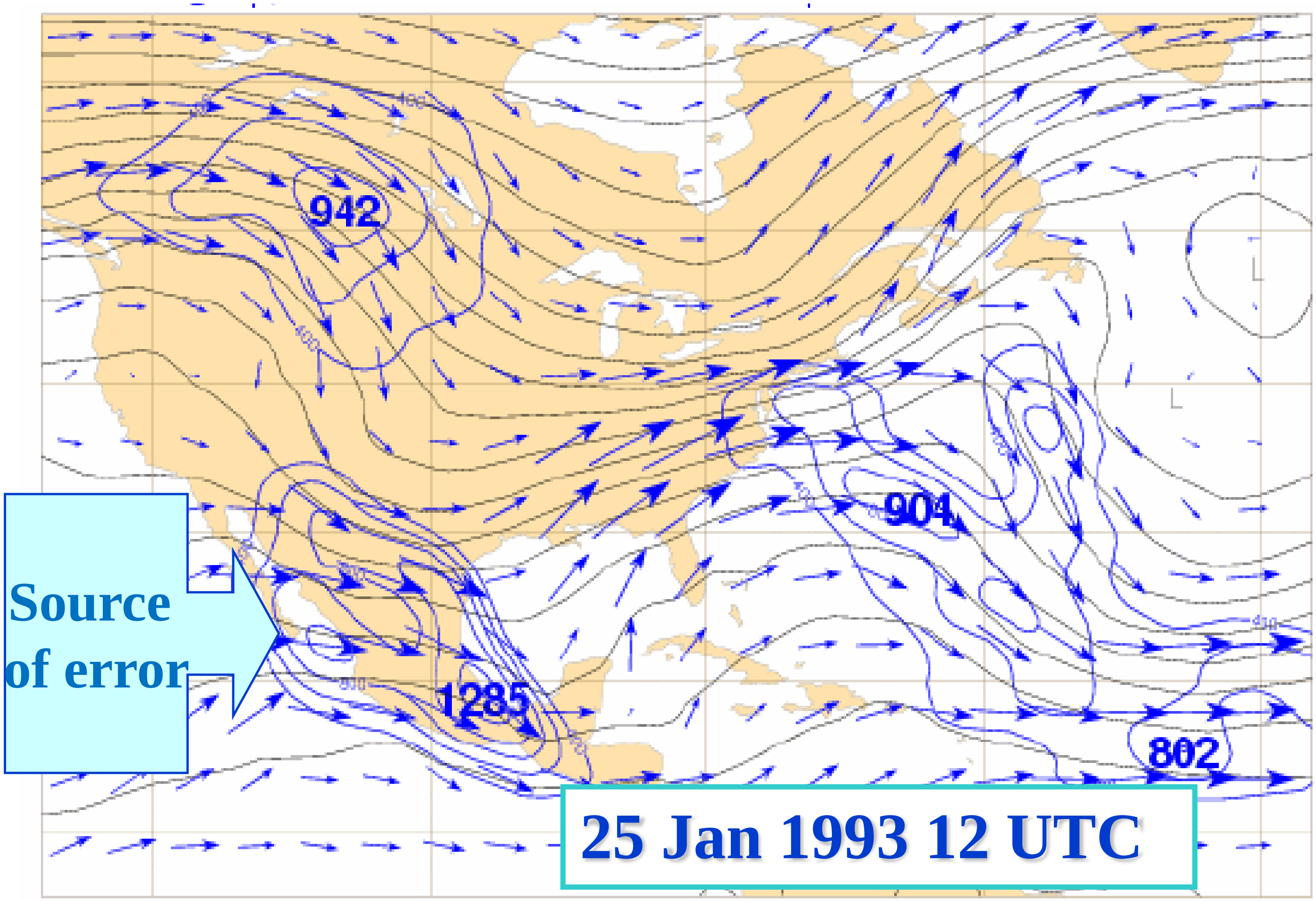
**D+5 from 24 Jan 1993 VT 29 Jan**

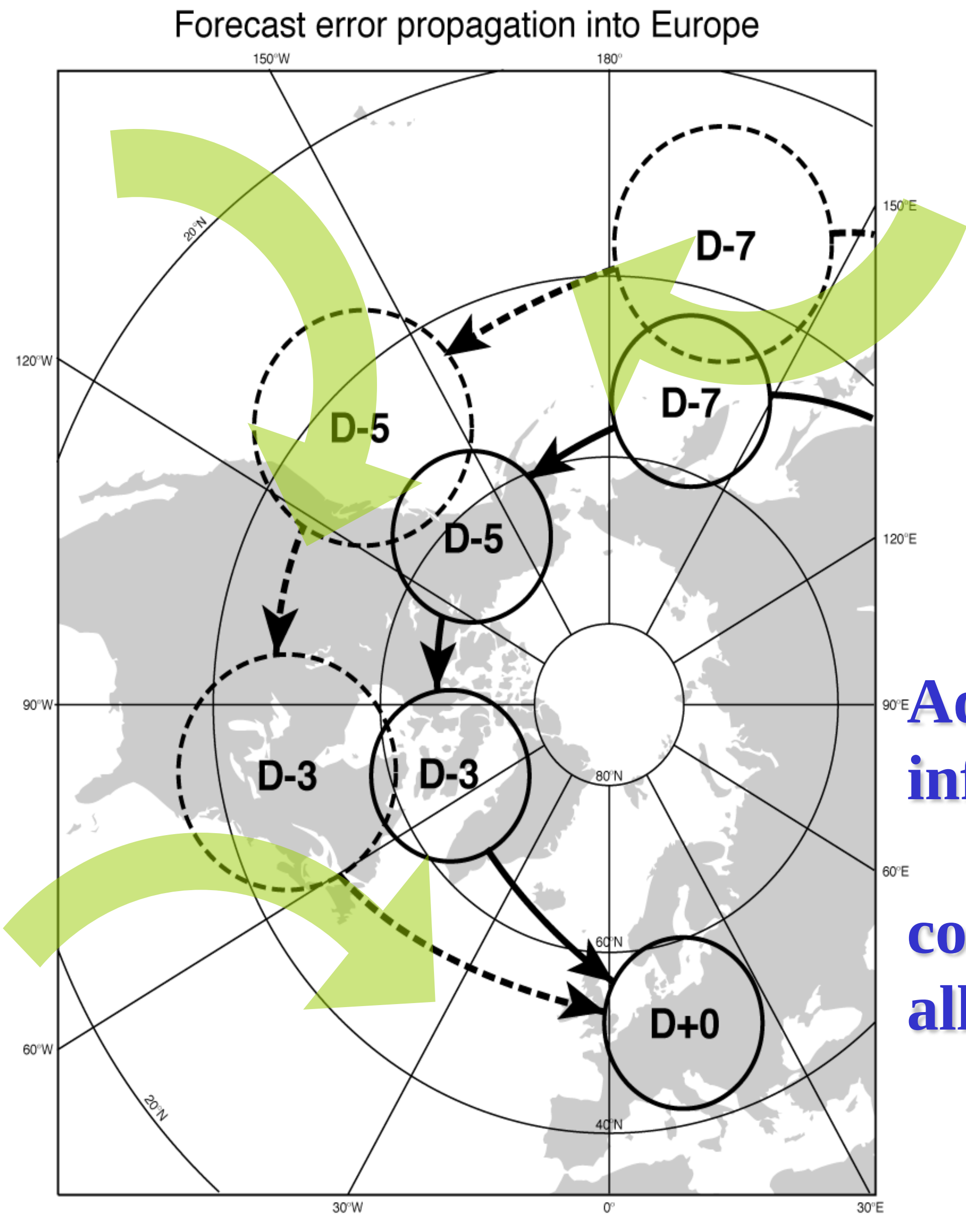



**D+4 from 25 Jan 1993 VT 29 Jan**



# The cause of the "jump" was traced back far upstream to an analysis change near the Mexican Gulf






**Forecast errors reach Europe with a speed of ~30 longitude deg/day, irrespective of season (thanks to the convergence of the meridians)**

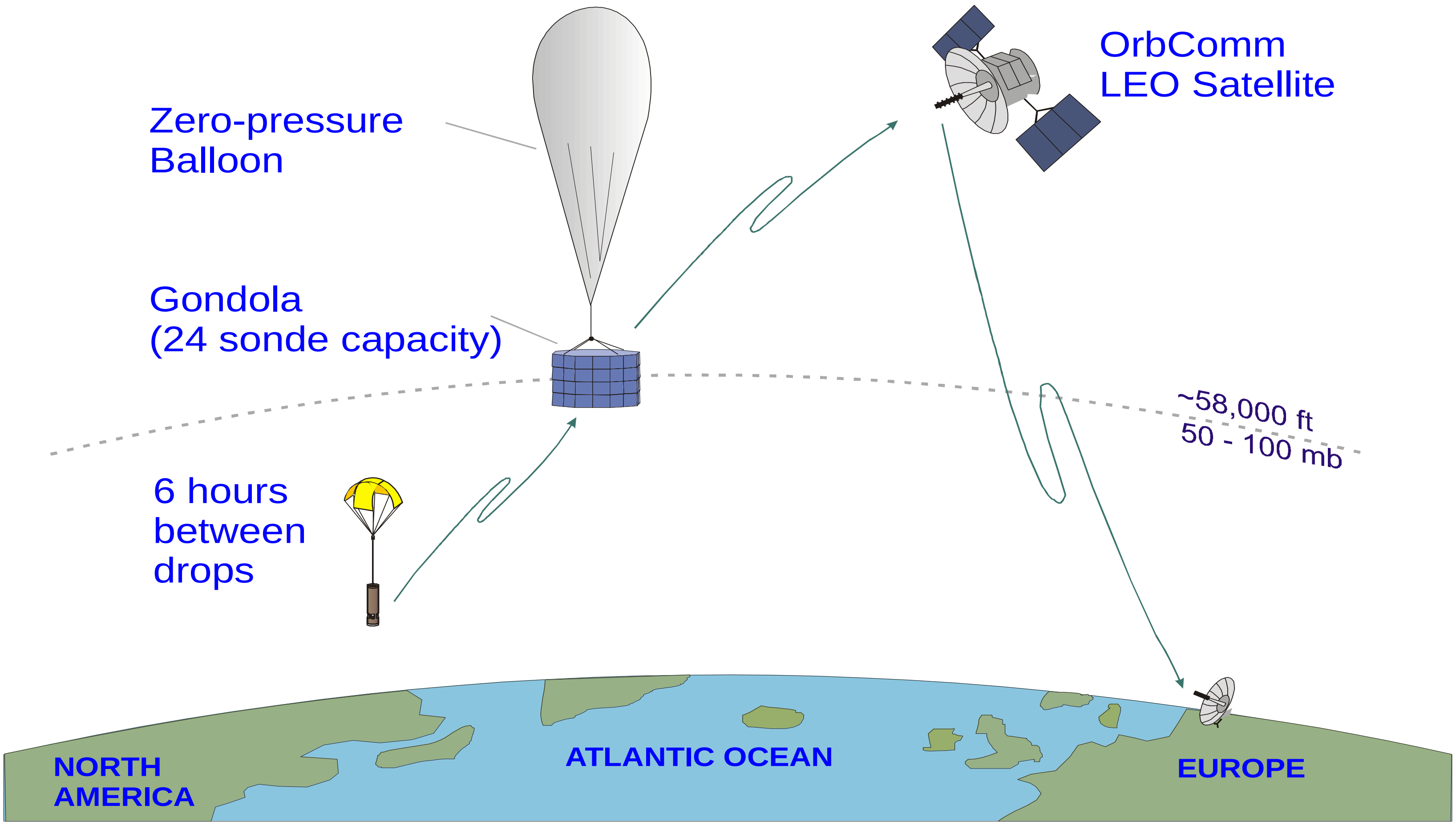
**Adding to this are the influences**



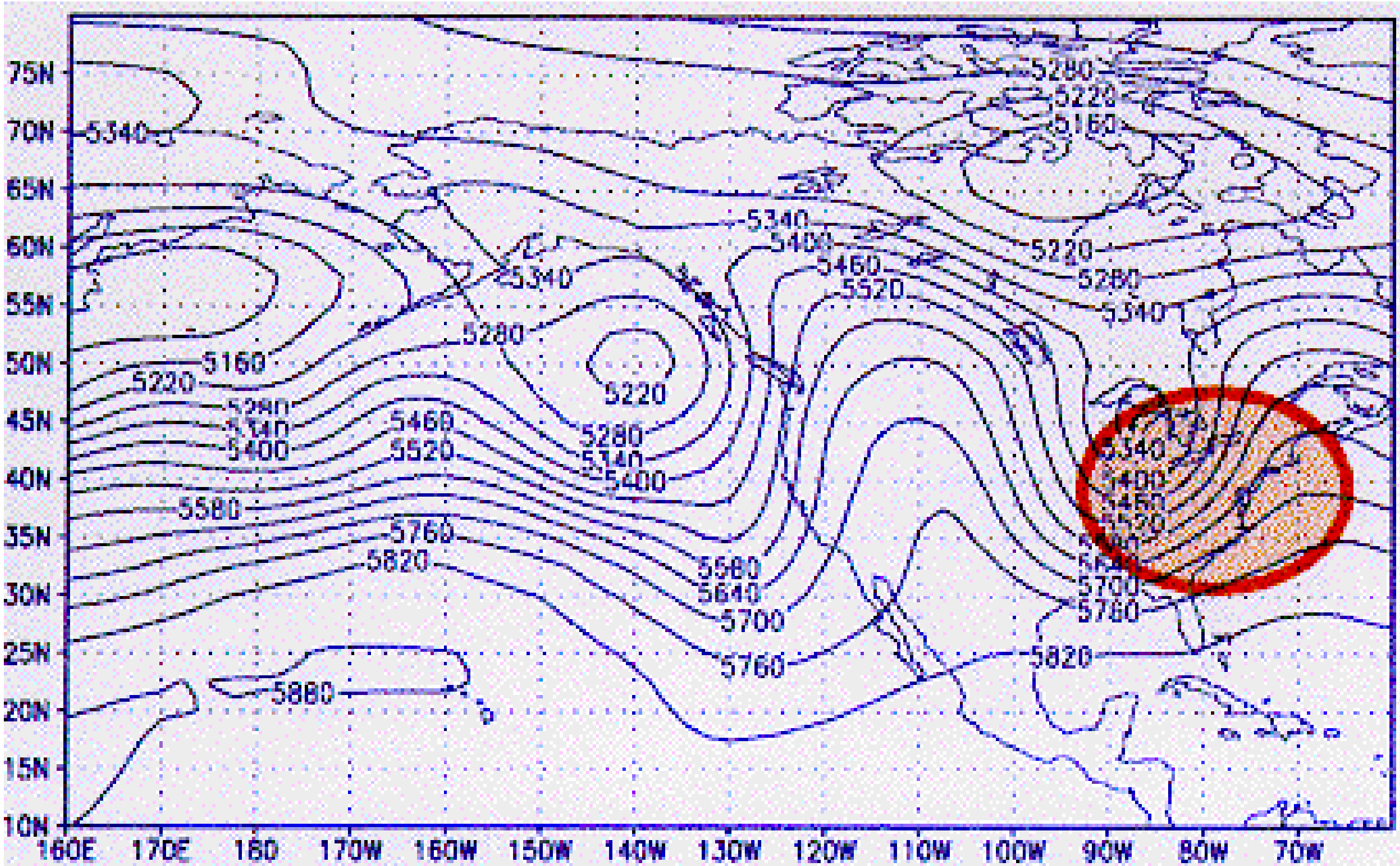
**coming from the Tropics at all seasons**

In particular in the US “group velocity thinking” is used, or has been used, to define where extra observations should be supplied

# Extra observations in the FASTEX experiment 1997

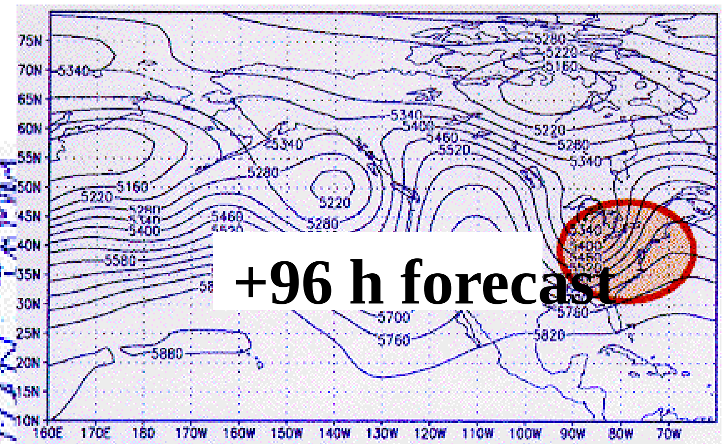


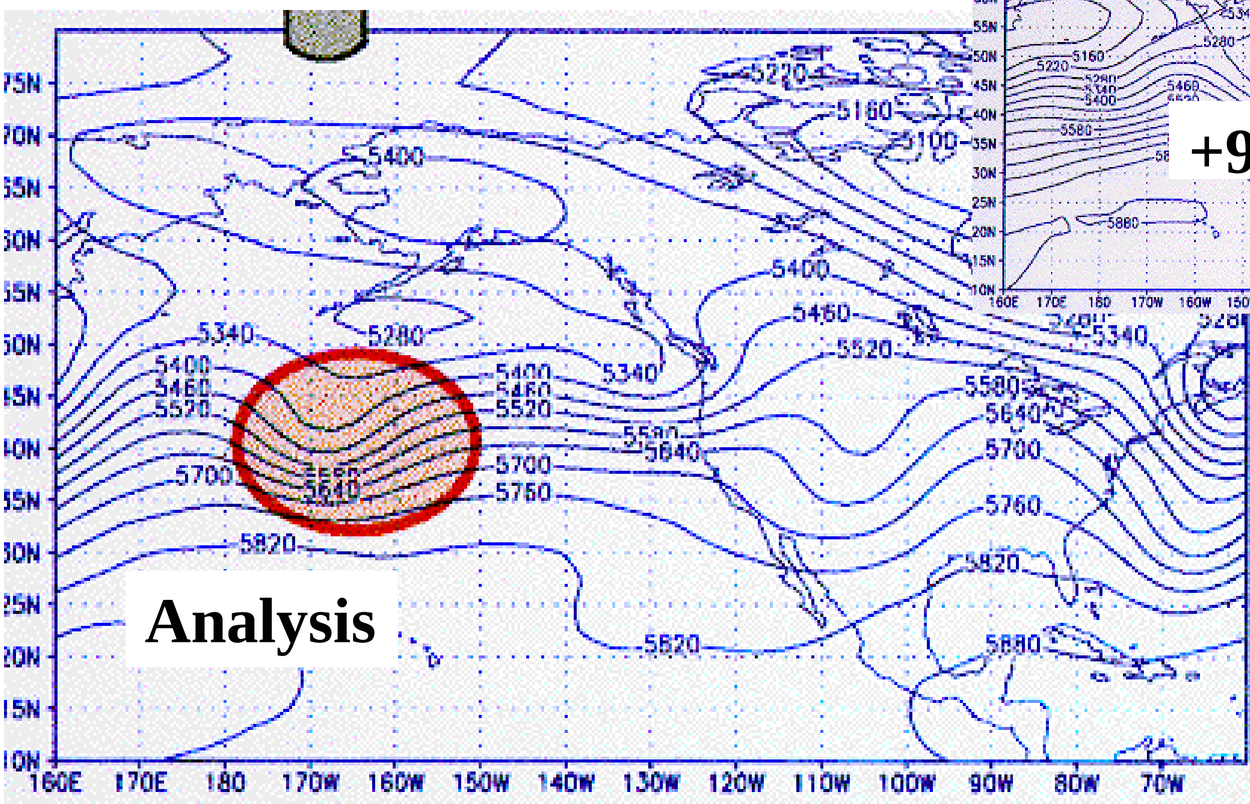
# An example from the NCEP by Zoltan Toht




A numerical +96 h forecast indicates a storm over eastern USA in four days time

Mathematical (adjoint or sensitivity) analyses point out a trough in the mid-Pacific as the likely target for extra observations. More and better observation here will improve the forecast.



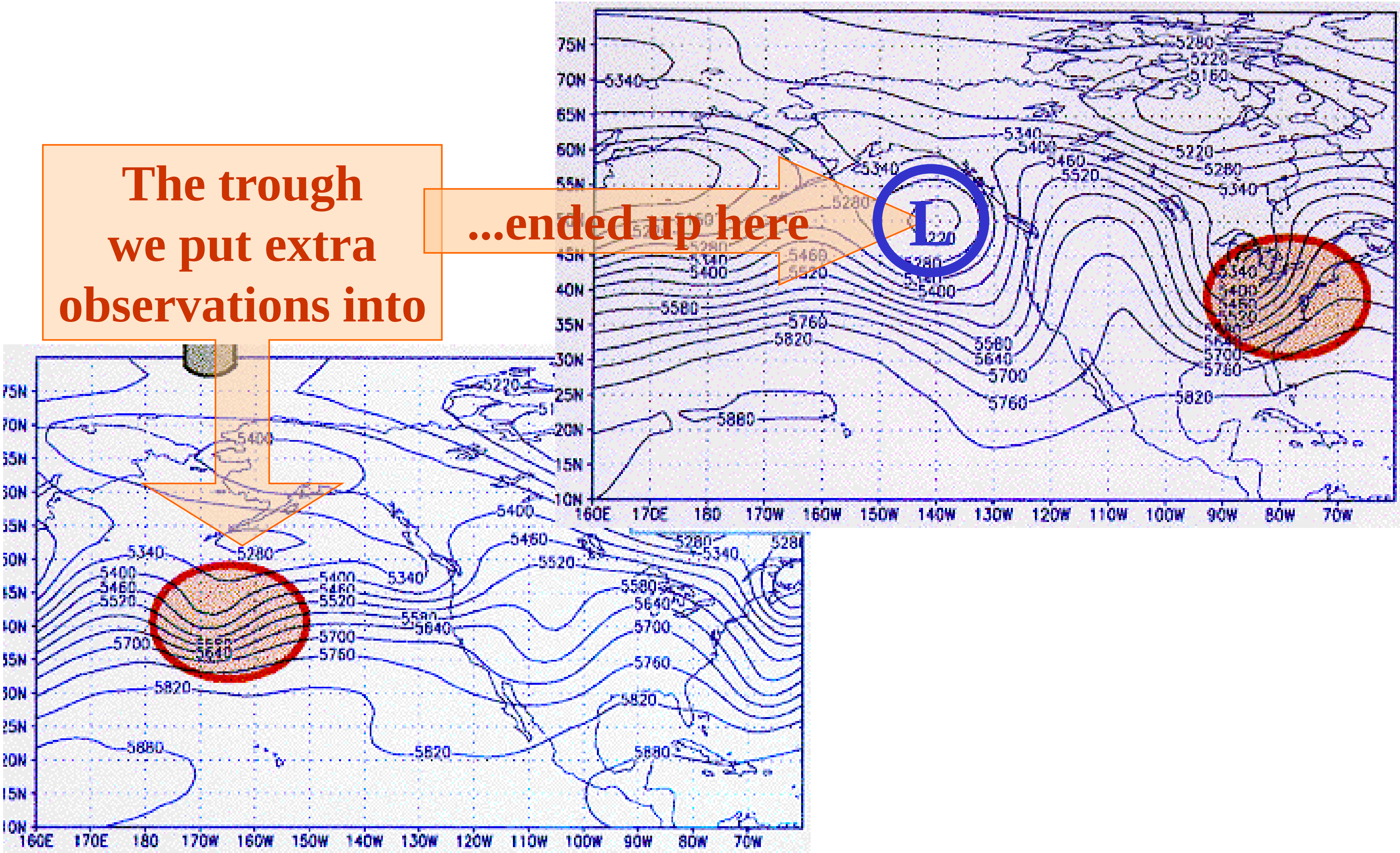



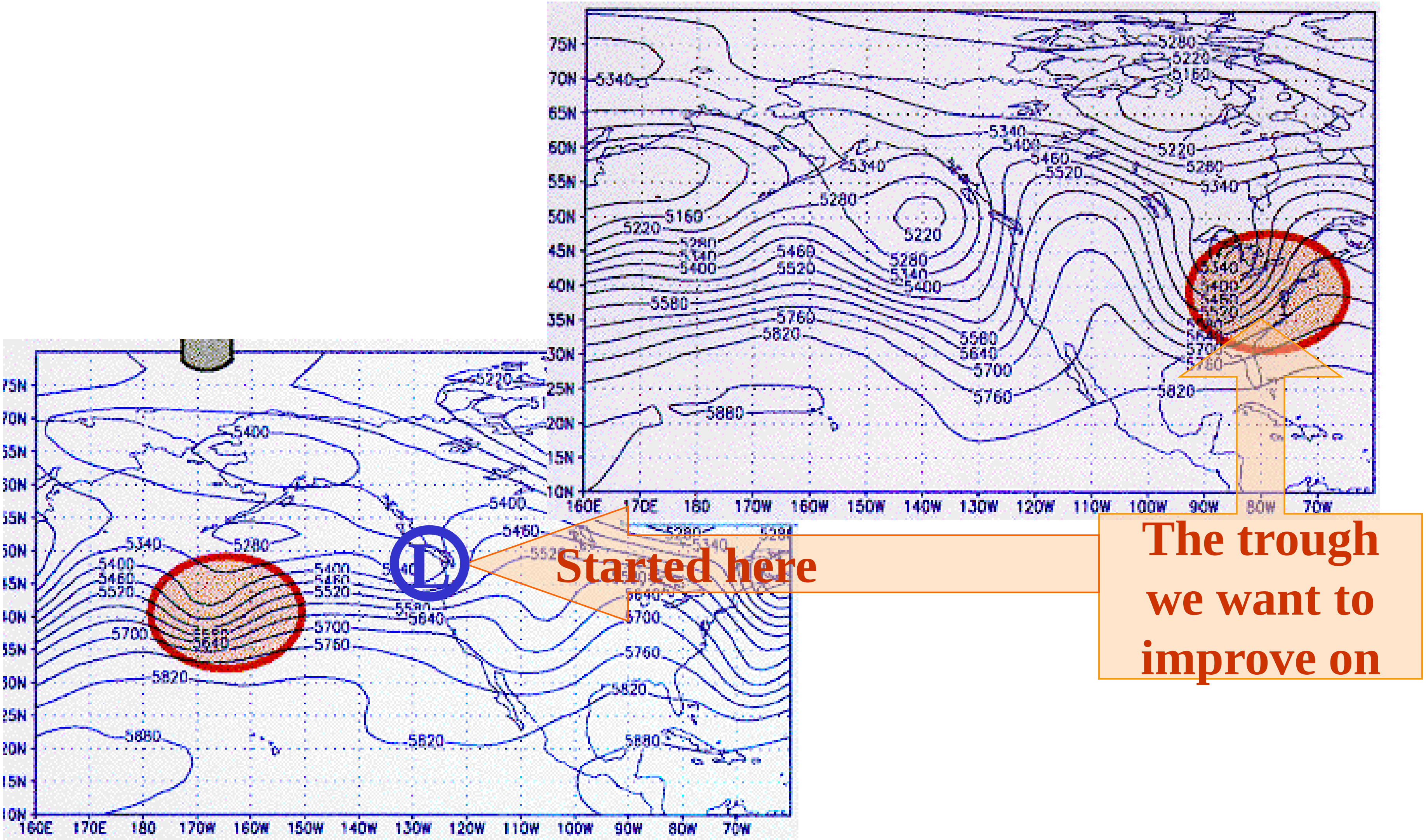

But are we looking at the same system?

# The answer is NO

The trough we put extra observations into

...ended up here




Started here
The trough we want to improve on

# End