Can one predict upper level winds in midlatitudes without knowledge of eddy mean flow interactions?

A thermodynamic view of baroclinic waves

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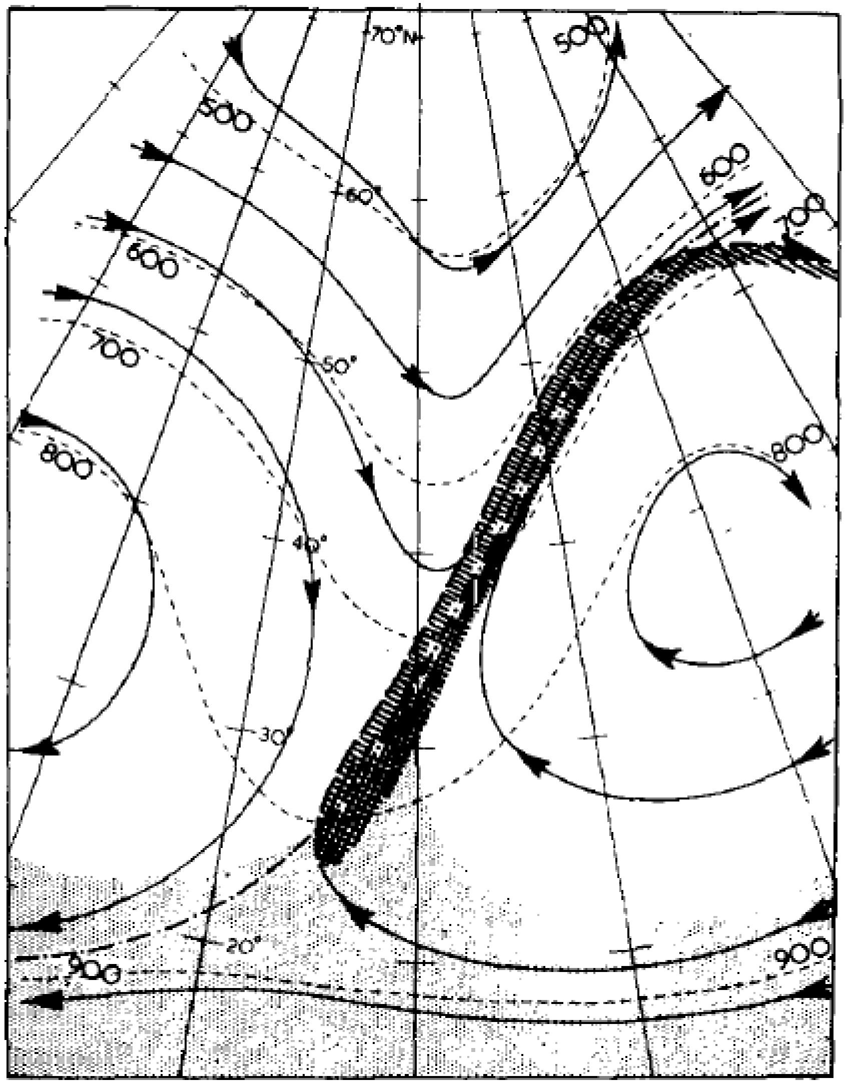
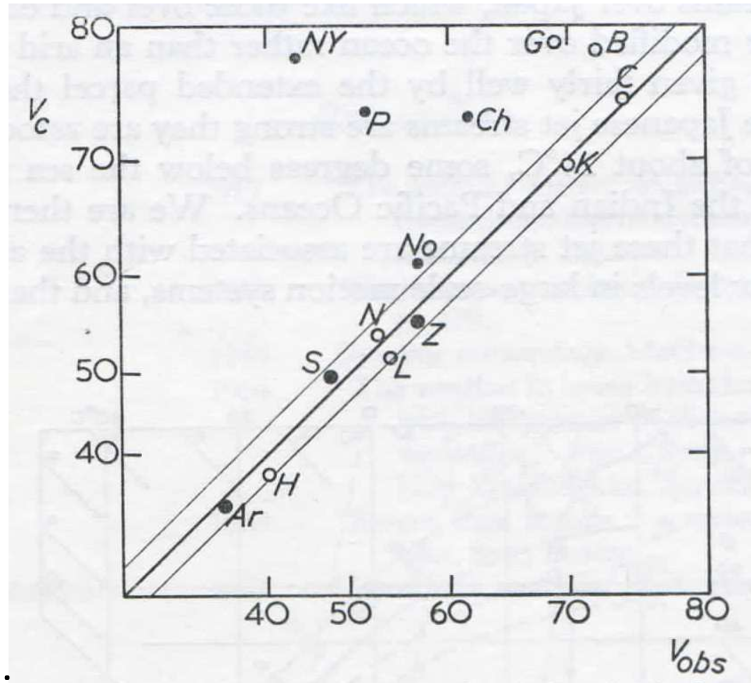
Motivation: the study by Green et al. (1966)



Schematic of the isentropic flow relative to a travelling wave

Strength of jetstream well predicted from application of Bernoulli's equation:

$$v_c^{\,2}/2+gz+c_pT+l_vq=cst$$



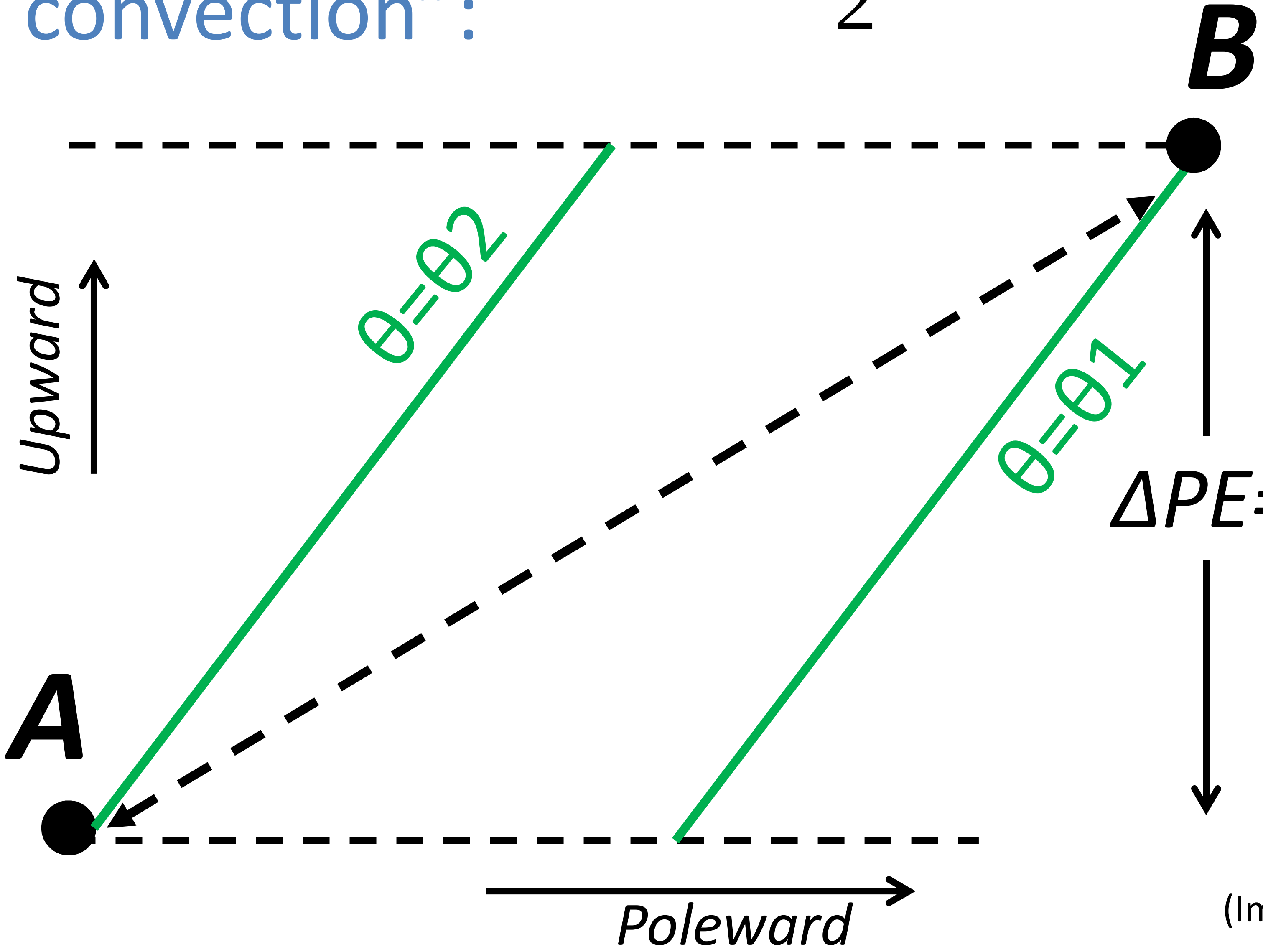
Objectives

- Test the existence of a link between low level heat content / SST and jetstream strength.
- If there is, assess the oceanic region of maximum influence.
- Do all this without studying eddy-mean flow interactions (!)

Part 1. A minimal model of baroclinic waves

“Sloping convection”:

$$\Delta KE \approx \frac{1}{2} N^2 \Delta z^2$$

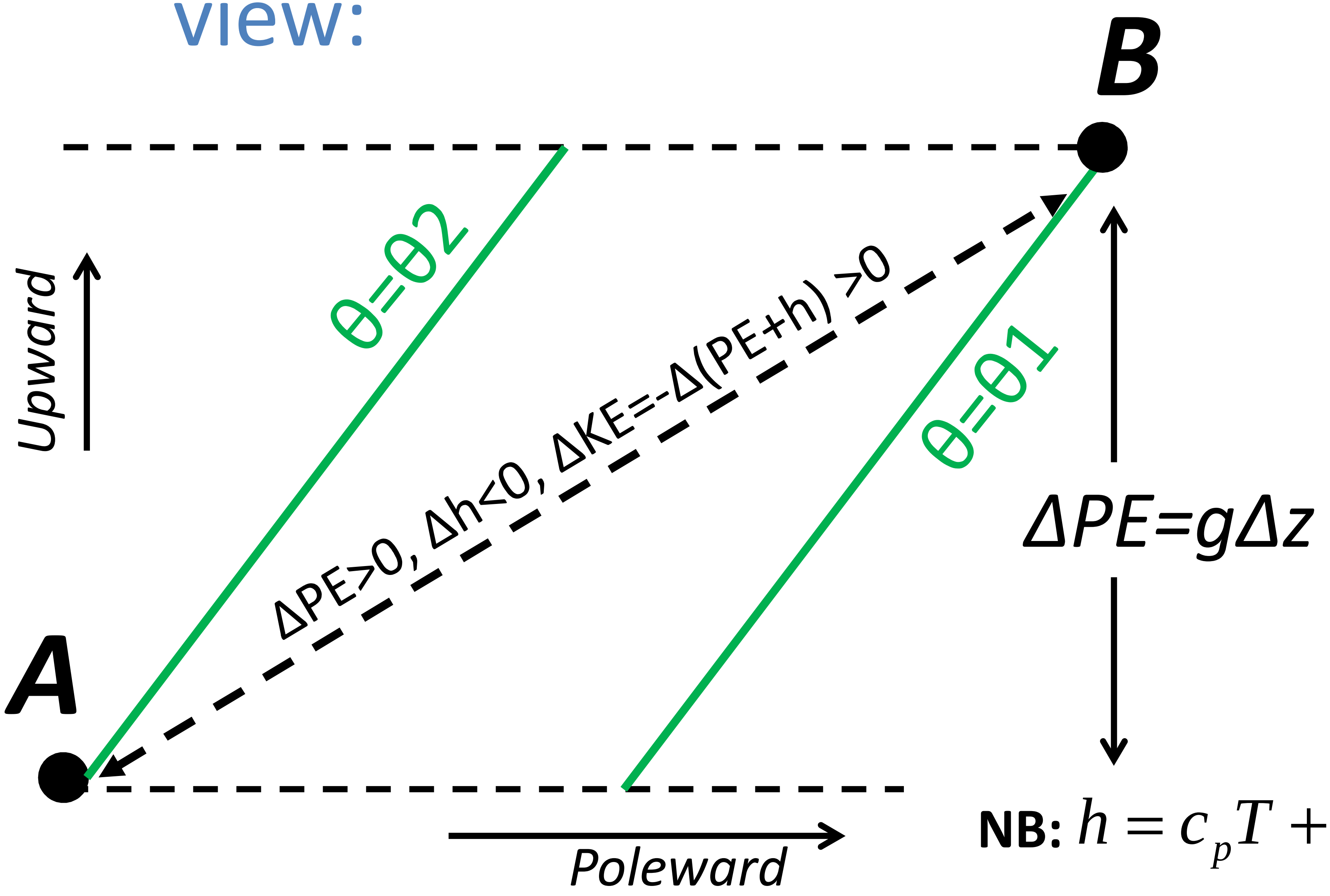


Eric Eady
(Imperial College!)

Thermodynamic view:

$$\Delta KE + \Delta PE + \Delta h \approx 0$$

(conservation of energy by a Lagrangian parcel)

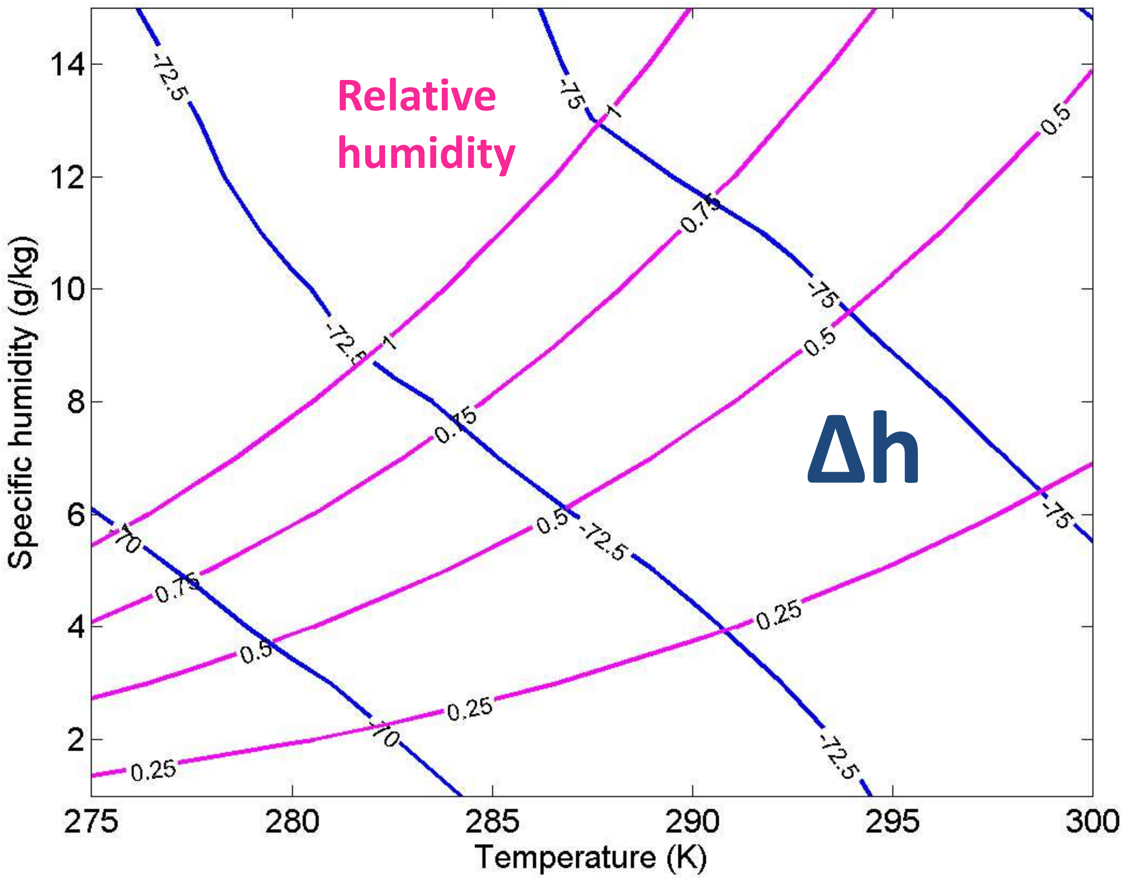


NB: $h = c_p T + l_v q$

The thermodynamic constraint: Δh≈Δh(SST)

- In a reversible moist adiabatic ascent from the top of the boundary layer (RH~cst), the loss of enthalpy Δh is a simple function of SST

Example of calculation between 800hPa & 300hPa



Combining dynamics & thermodynamics

- Consider energy conversion during adiabatic ascent,

$$\Delta KE + \Delta PE = -\Delta h = |\Delta h|$$

- And the previous equation,

$$\Delta KE = \frac{1}{2} N^2 \Delta z^2 - \Delta KE_o$$

- With:

$$\Delta PE = g\Delta z$$

Combining dynamics & thermodynamics

- Solving the 2nd order polynomial:

$$\boxed{\Delta PE = \left(\tfrac{g}{N}\right)^2 \left(\sqrt{1 + \frac{2(|\Delta h| + \Delta KE_o) N^2}{g^2}} - 1 \right)}$$

$$\boxed{\Delta KE = -\Delta KE_o + \frac{1}{2}\left(\frac{g}{N}\right)^2 \left(\sqrt{1 + \frac{2(|\Delta h| + \Delta KE_o) N^2}{g^2}} - 1 \right)^2}$$

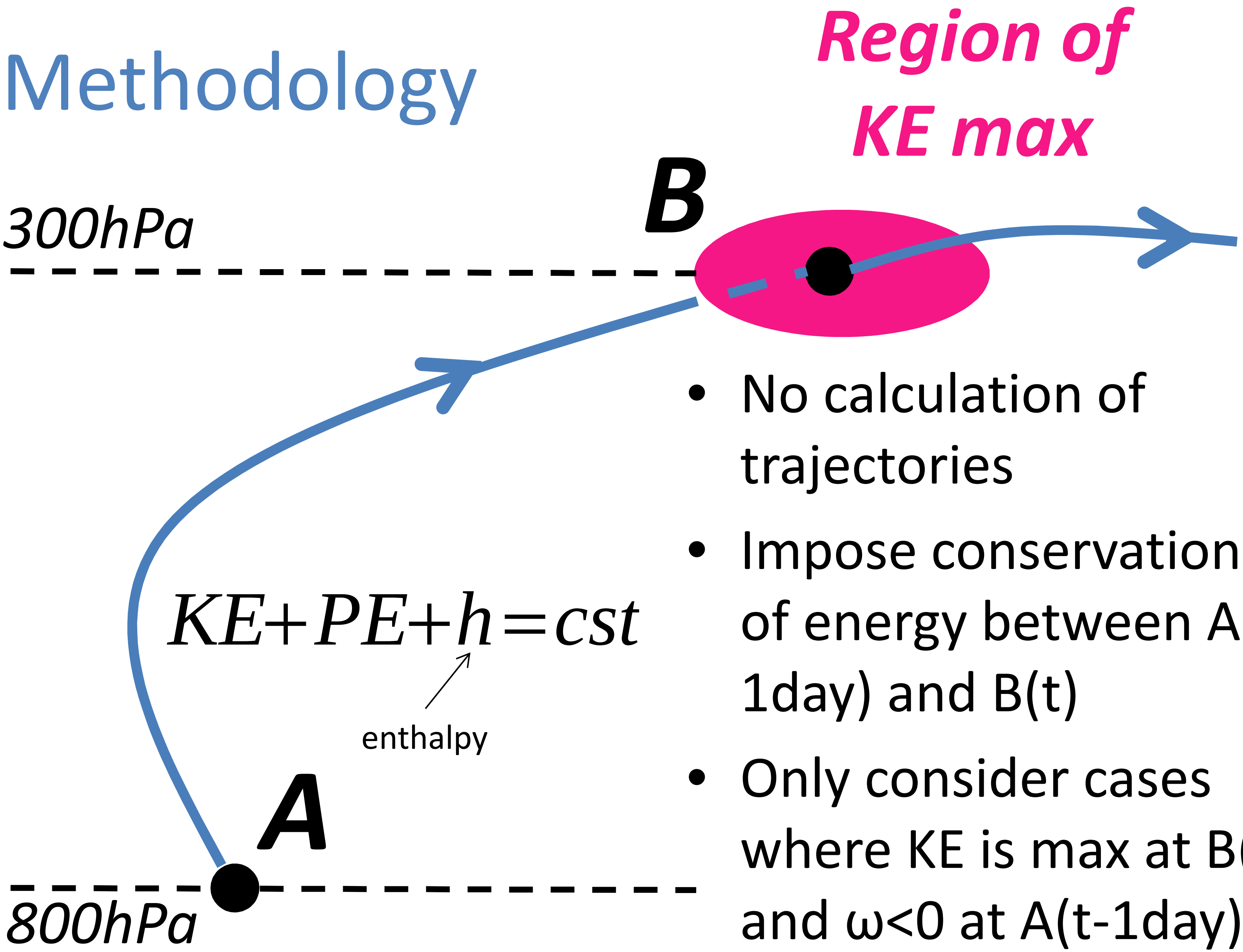
- Small parameter:

$$\varepsilon \equiv (|\Delta h| + \Delta KE_o)/(g/N)^2 \approx |\Delta h|/(g/N)^2 << 1$$

Part 2. Testing the predictions against “observations”

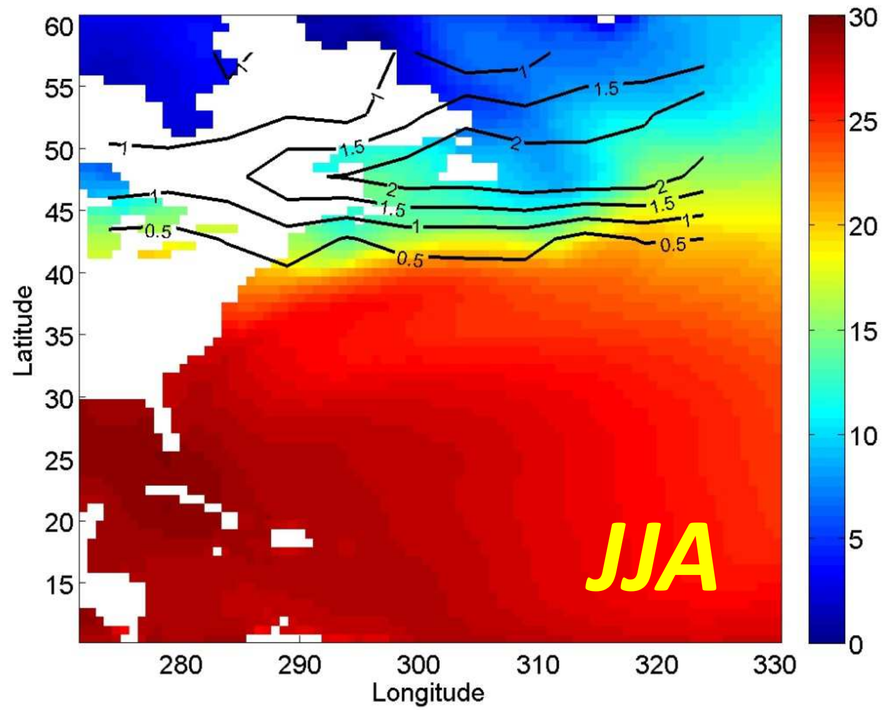
- ERA interim data
- Daily (12.00 UTC)
- 1980-2012 (December through February)

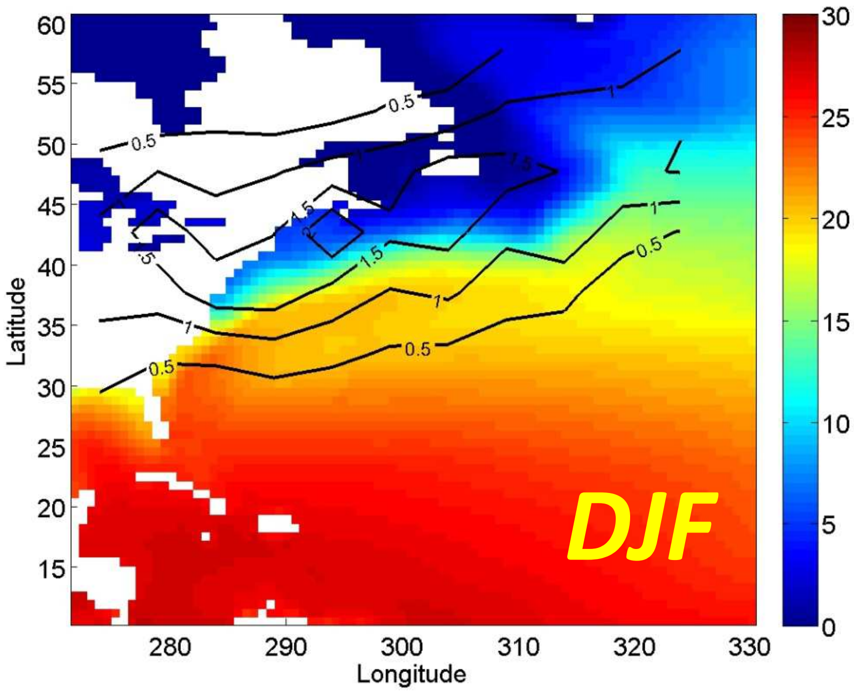
Methodology



- No calculation of trajectories
- Impose conservation of energy between A(t-1day) and B(t)
- Only consider cases where KE is max at B(t) and $\omega<0$ at A(t-1day)

Number of KEmax events within 5º X 5º boxes per season

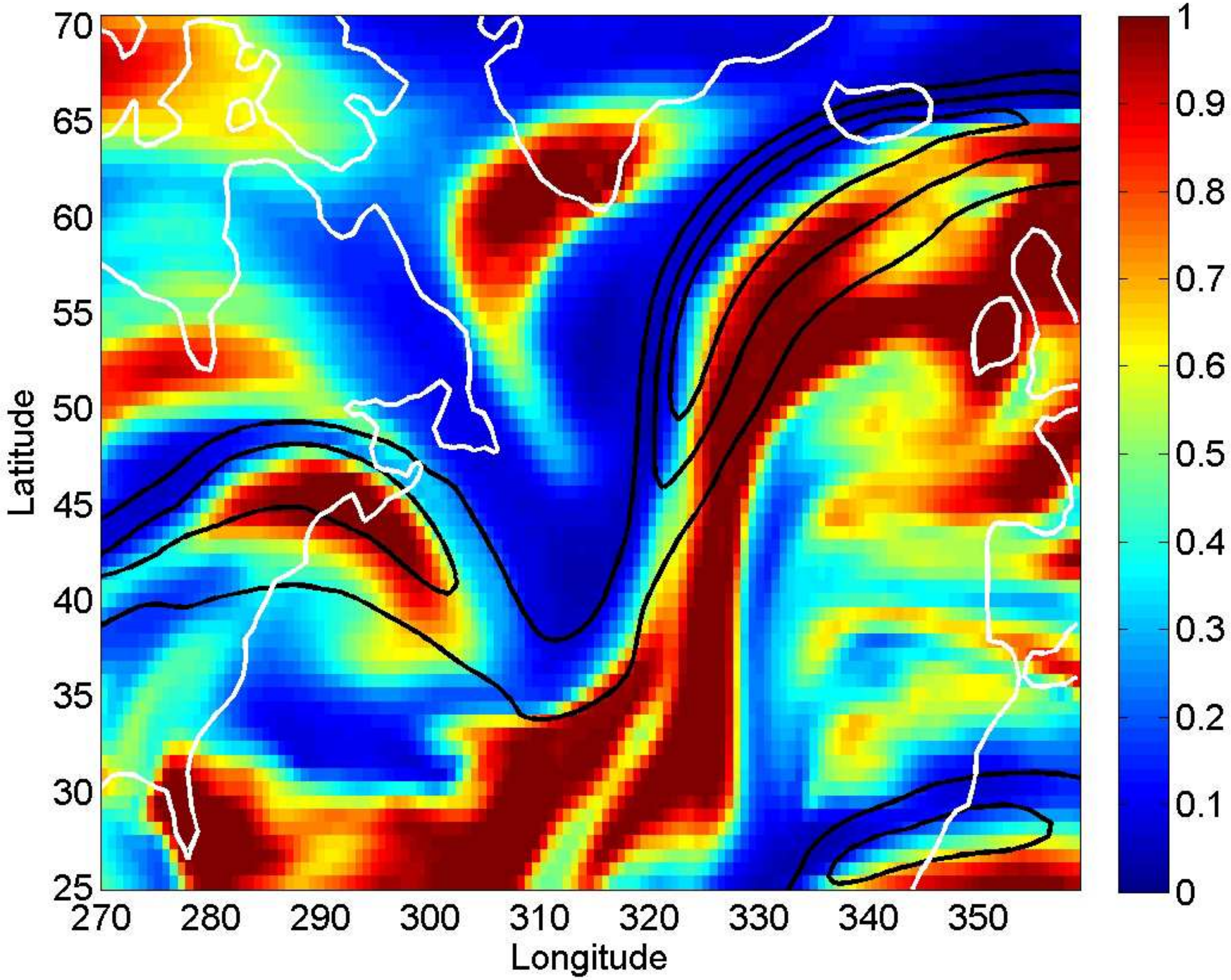




→ Rare events at a given location, but always present somewhere on a given day

An example of snapshot at 300hPa

(KE in black CI=1kJ/kg, relative humidity in color)

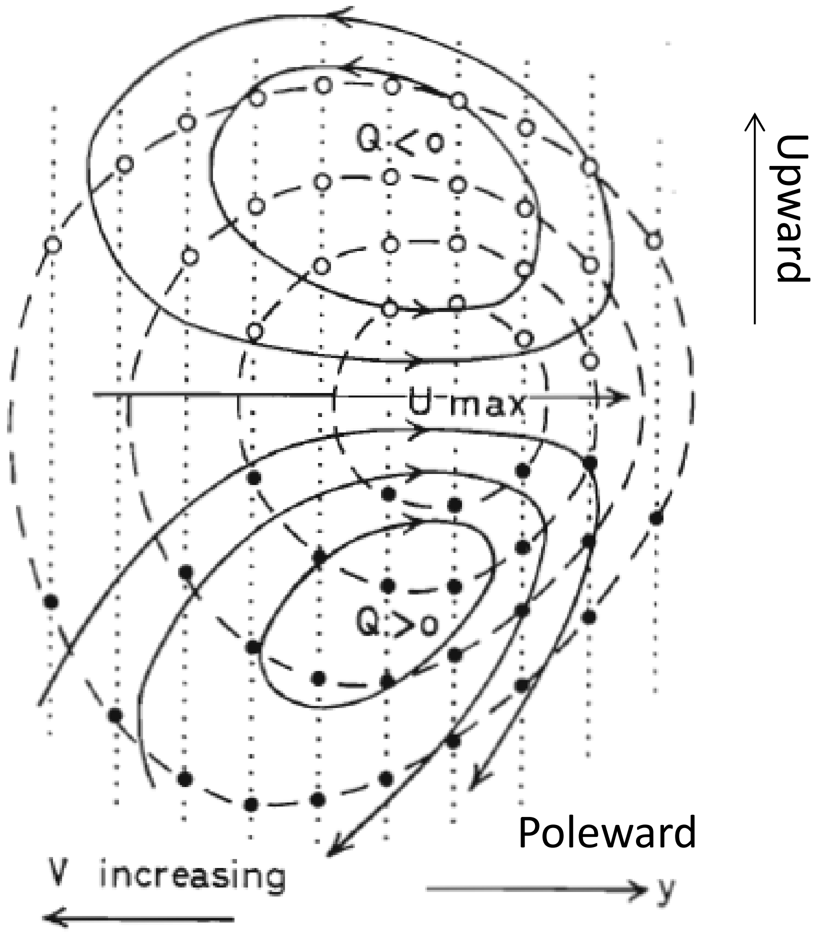


Relationship between KEmax and upper level relative humidity

- Expect moist air on the equatorward flank of the jet (below jet core)

- Expect a mix of dry and moist air at the core of the jet

NB: streamlines in (y,p) coordinates so representative of mass transport



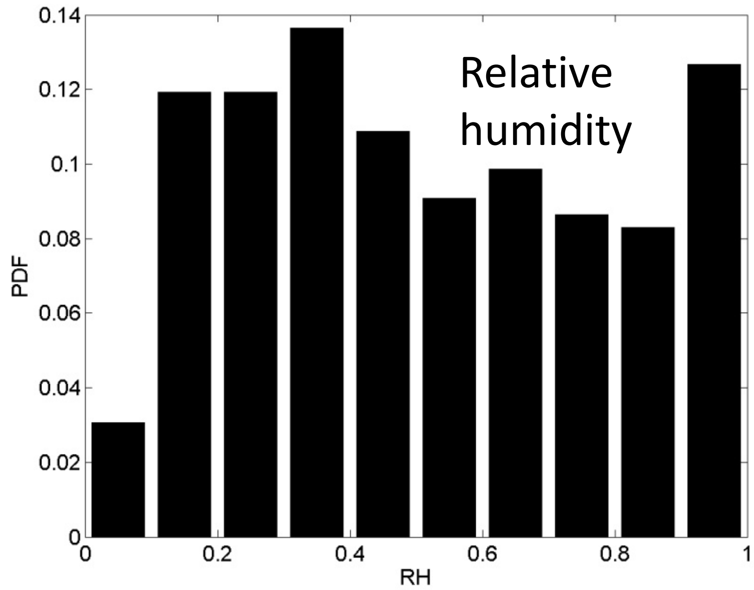
Eliassen (1962)

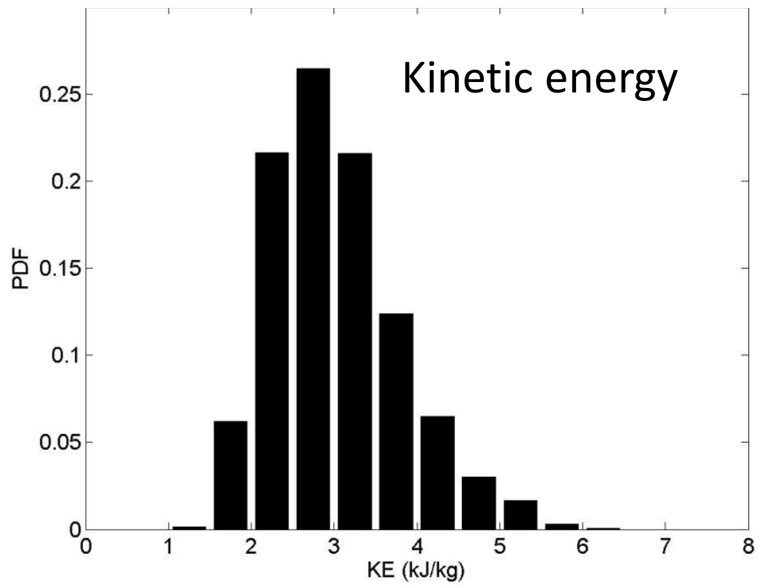
PDFs for KE max events at 300hPa
(ERAinterim, DJF 1980-2012)

- About 40% of the events have RH>0.6

- The distribution peaks near KE = 3kJ/kg (U~77m/s).

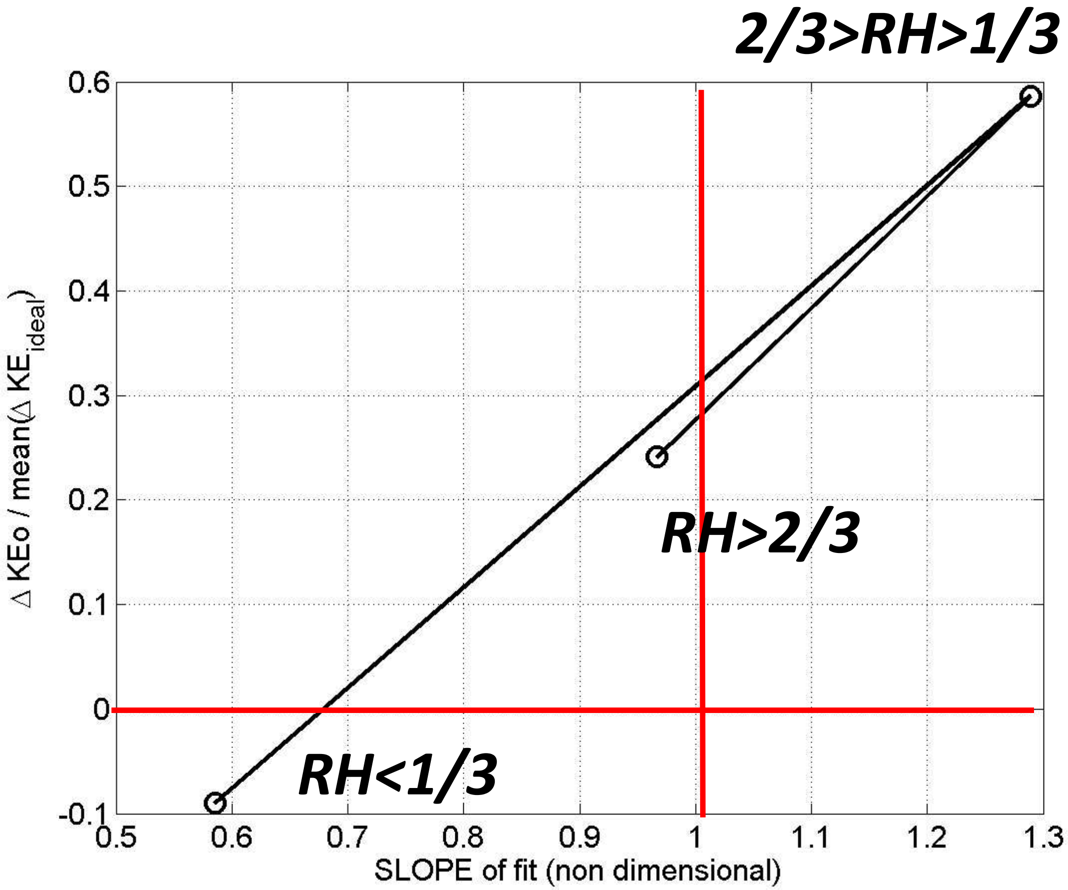
- Suggestion that moist profiles (RH>0.6) have stronger low level ascent and broader distribution of KE (not shown here).





Test of the model:
$\Delta KE(obs)=\Delta KE_{ideal} - \Delta KEo$

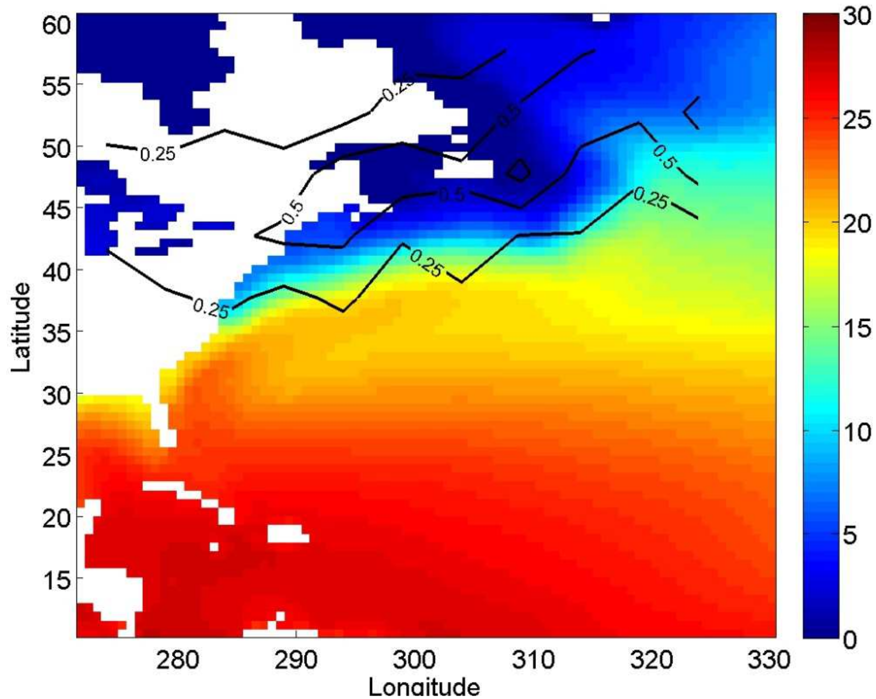
- Model is in best agreement with observations for KEmax events with relative humidity RH>2/3



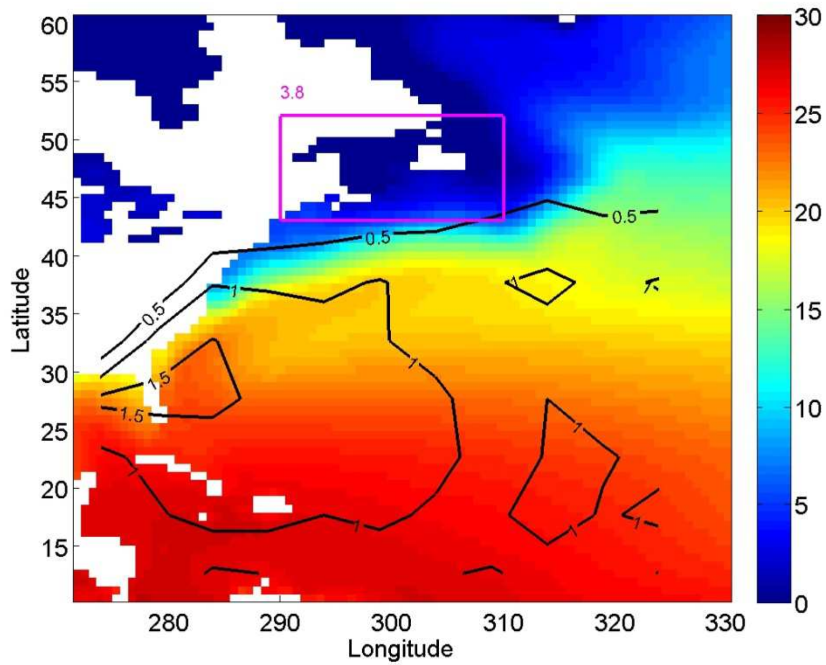
NB: results shown are for winter averages. Daily calculation for RH>2/3 has a slope ~0.7

KEmax events with RH>2/3

- Number of events per winter within 5 X 5 degree boxes



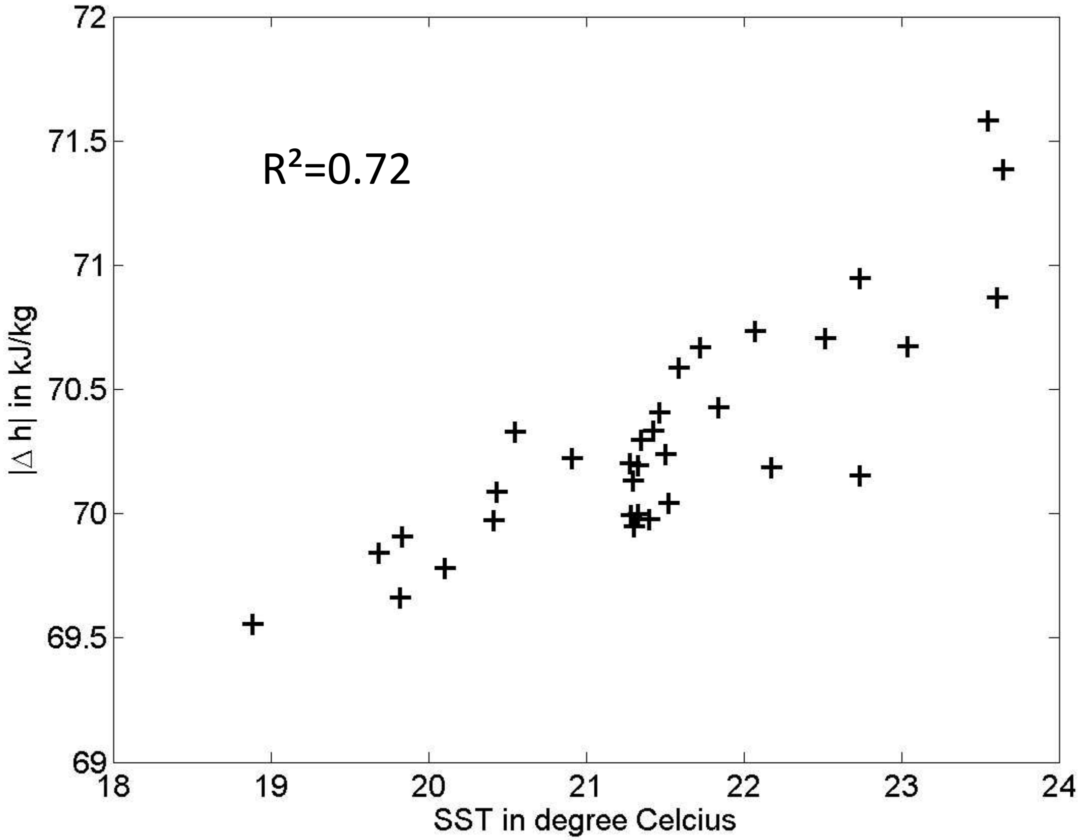
- Number of events with the right energy at low level ***one day earlier*** (again within 5X5 degree boxes)



Link between SST and Δh for KEmax events with RH>2/3

- As SST increases, |Δh| increases

- However, the buffer effect of moist adiabats limits the sensitivity of Δh to SST (slope~3kJ/kg per 6K)

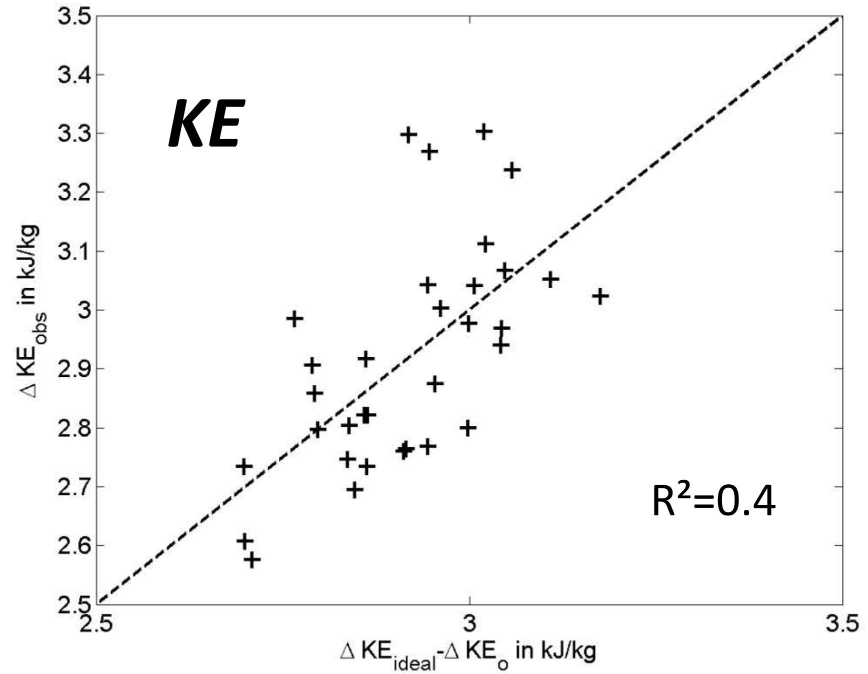


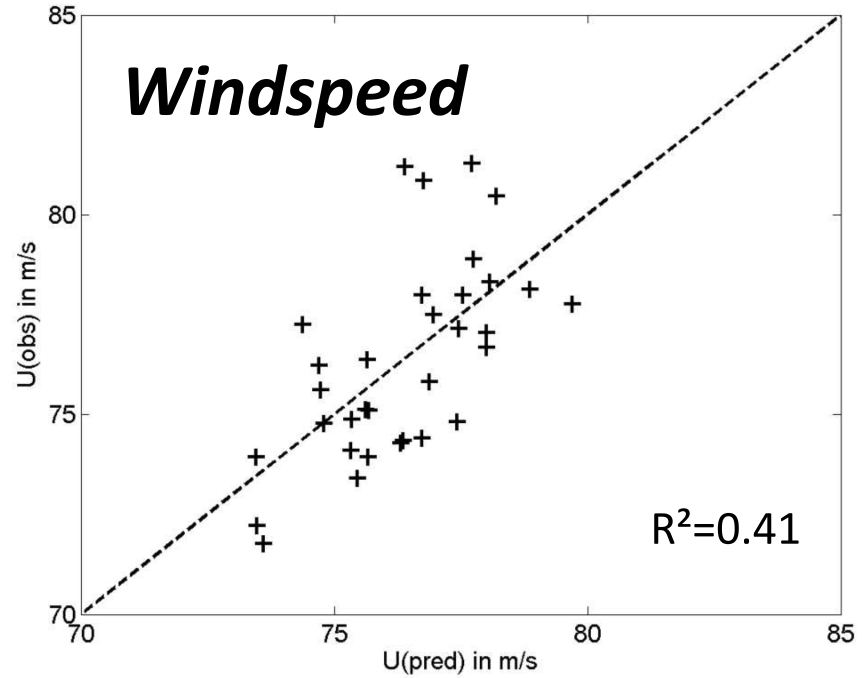
NB: for this and subsequent scatterplots, one cross for each winter (averaging of daily calculations)

Test of the model: actual scatter plots for KEmax events with RH>2/3

$$\Delta KE \approx \frac{1}{2}\left(\frac{N}{g}\right)^2 |\Delta h|^2 - \Delta KE_o$$

- Good agreement considering the minimal GFD information

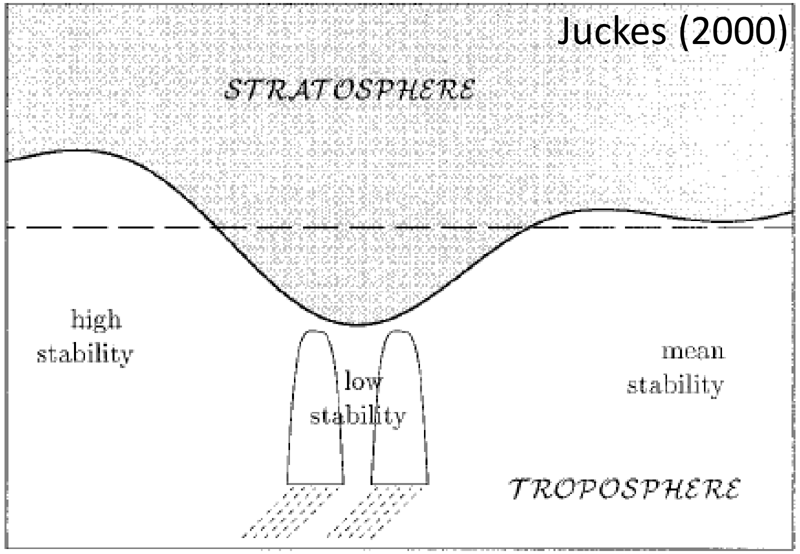


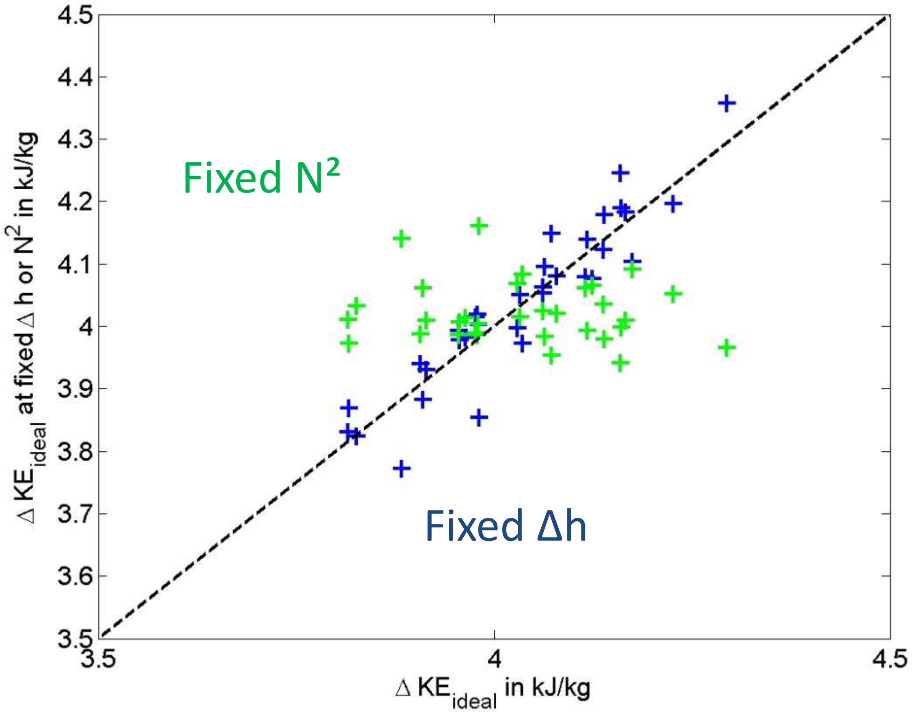


Test of the model: actual scatter plots for KEmax events with RH>2/3

- winter-to-winter variability in ΔKE is driven by changes in N^2, not by changes in Δh.

$$\Delta KE \approx \frac{1}{2}\left(\frac{N}{g}\right)^2 |\Delta h|^2 - \Delta KE_o$$





Summary

- There is skill in predicting jets from simple energetic arguments:

$$KE \sim (\Delta h)^2 N^2, \quad \Delta h = \Delta h(SST)$$

enthalpy change upon moist adiabatic ascent in the warm conveyor

- For North Atlantic "moist" jets, the most likely source of ascent coincides with the "warm tongue" of the Gulf Stream at subtropical latitudes.

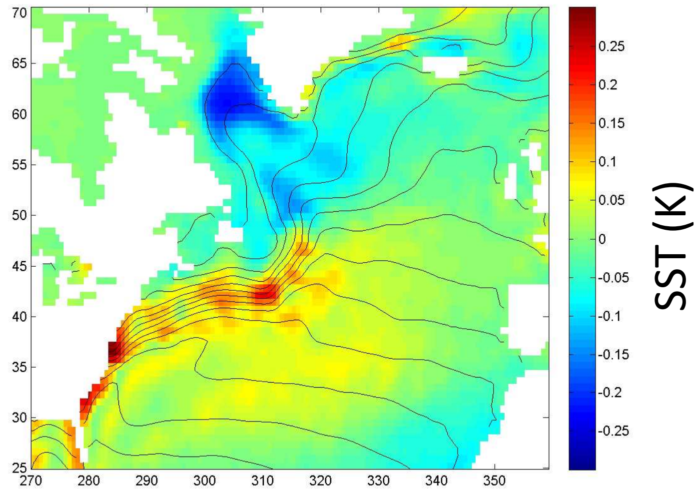
- The SST impact on Δh is mostly through moisture (destabilizing) and is buffered by an enhancement of the moist stratification (stabilizing)

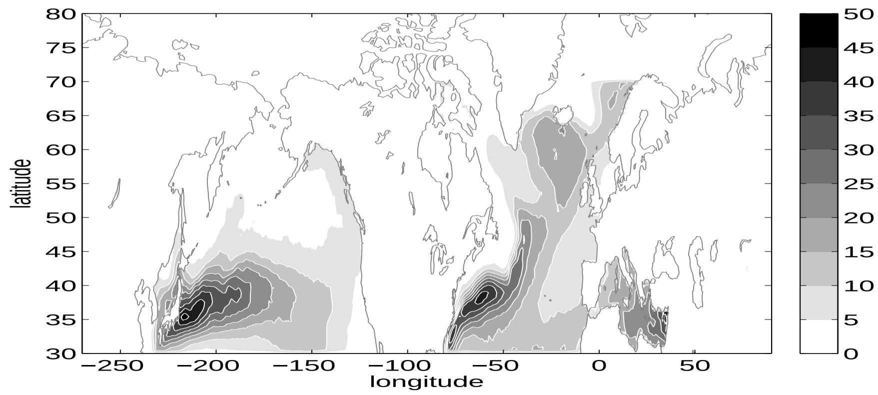
- As a result, the variability of winter-to-winter upper level KE is dominated by changes in stratification.

Implications for North Atlantic ocean-atmosphere interactions

- The thermodynamic control $\Delta h(SST)$ is qualitatively relevant to the positive feedback between the NAO/SST tripole interaction, but likely to be weak.
- The real "leverage" is on the oceanic control of N^2.

MCA analysis U300/SST
(DJF average, 1980-2012)





Sheldon et al. (2014)

extras

Implication of the model for a detection of an oceanic influence on the jet stream

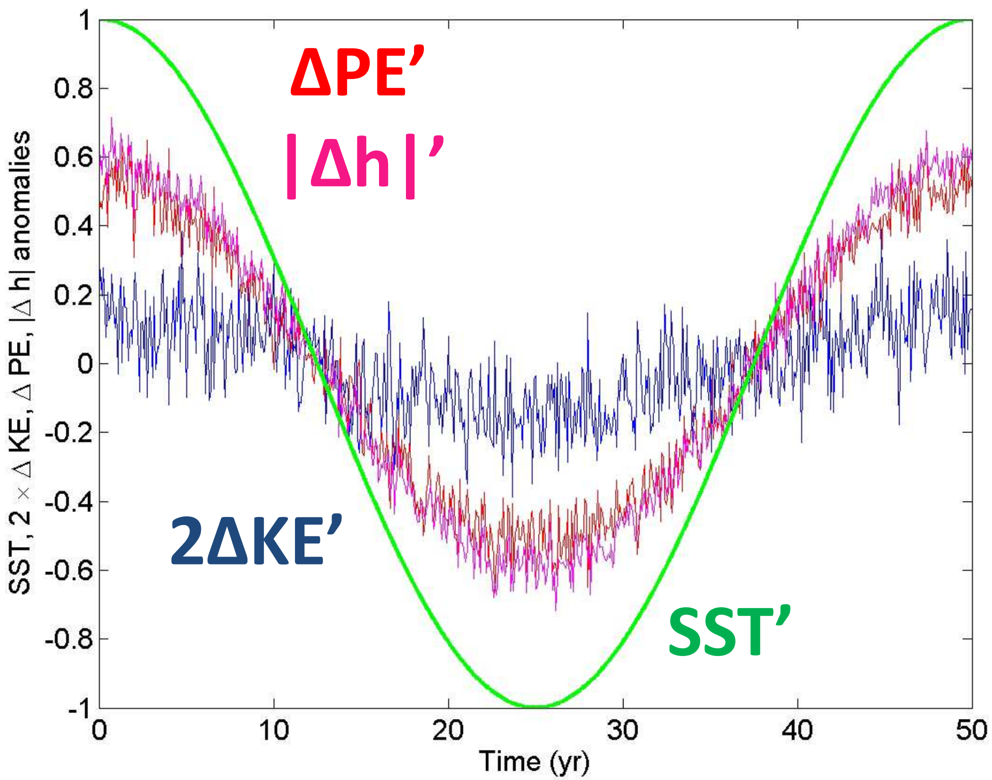
- The dependence of KE on low level heat content is multiplicative:

$$\Delta KE \sim (\Delta h)^2 N^2$$

$$\Delta PE \sim \Delta h$$

which might be the fundamental reason why it is so difficult to extract an oceanic forcing in the extra-tropics.

Statistical model: <u>500</u> ensemble members



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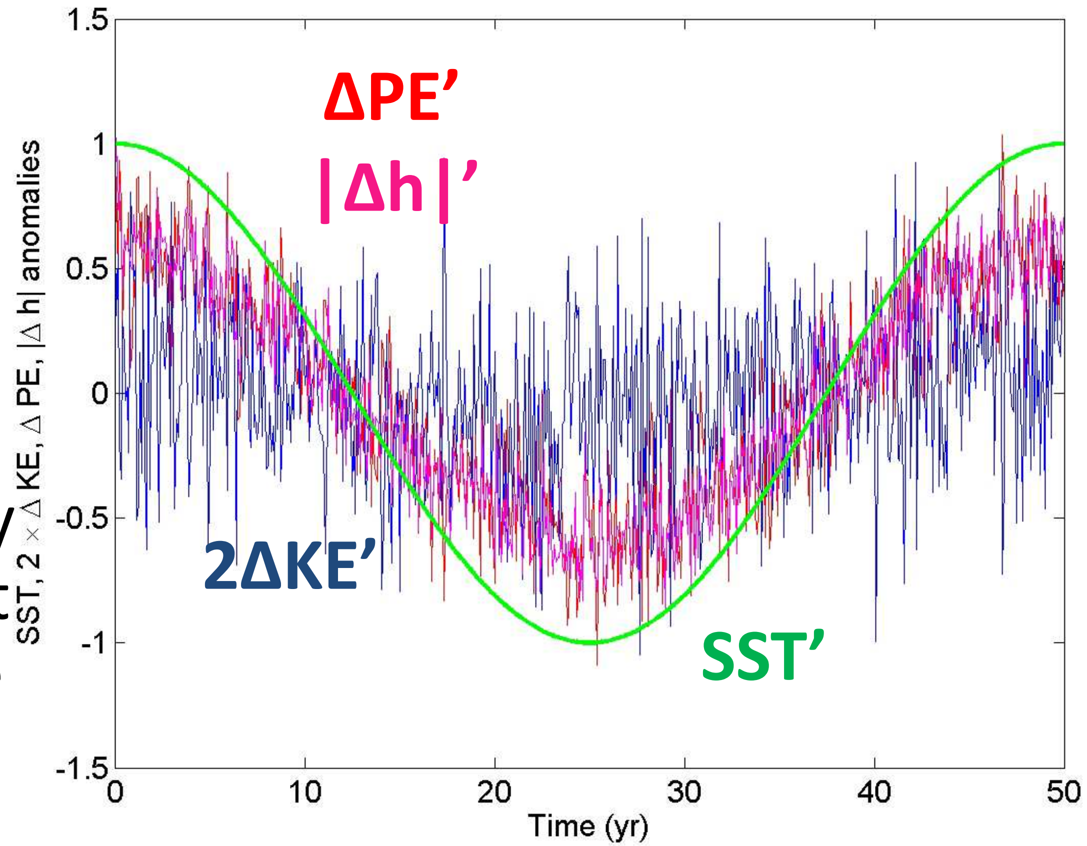
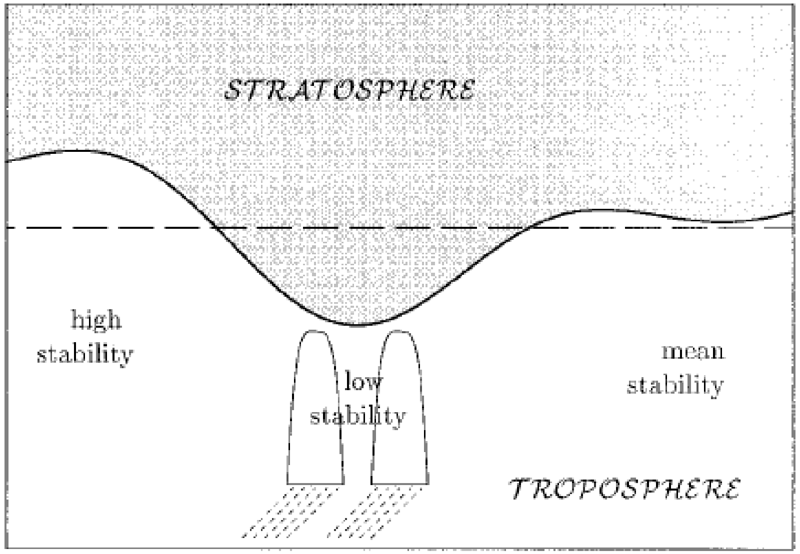
Statistical model: <u>50</u> ensemble members

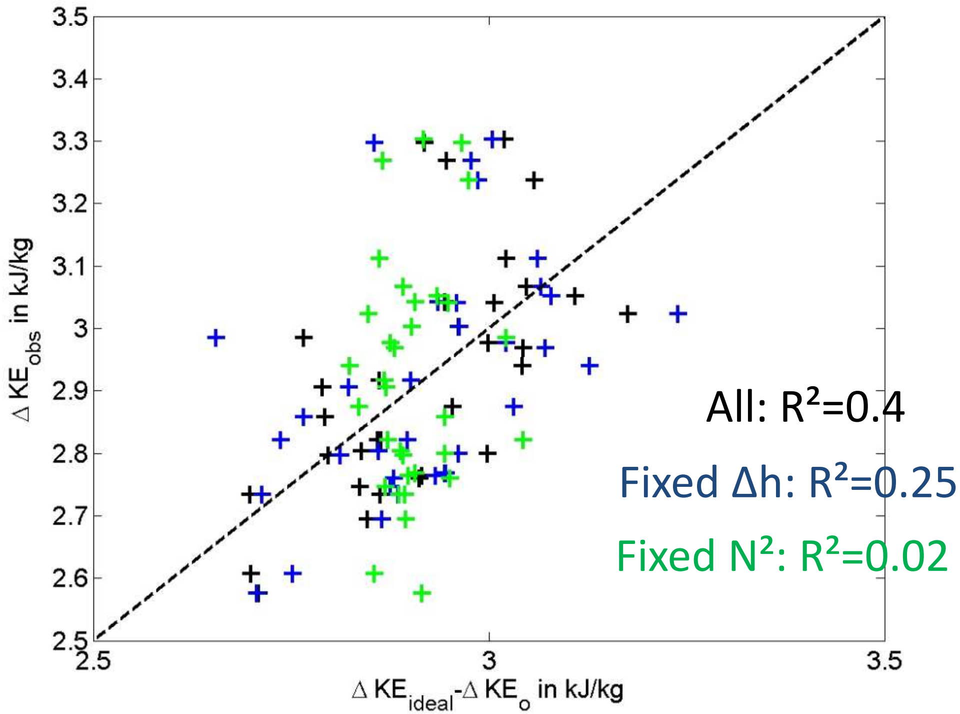


Test of the model: actual scatter plots for a threshold RH = 2/3

- Yr-to-yr variability in ΔKE is driven by changes in N^2, not by changes in Δh.

$$\Delta KE \approx \frac{1}{2}\left(\frac{N}{g}\right)^2 |\Delta h|^2 - \Delta KE_o$$





Background

- Conservation of the Bernoulli function B (=KE+PE+enthalpy) following a fluid parcel,

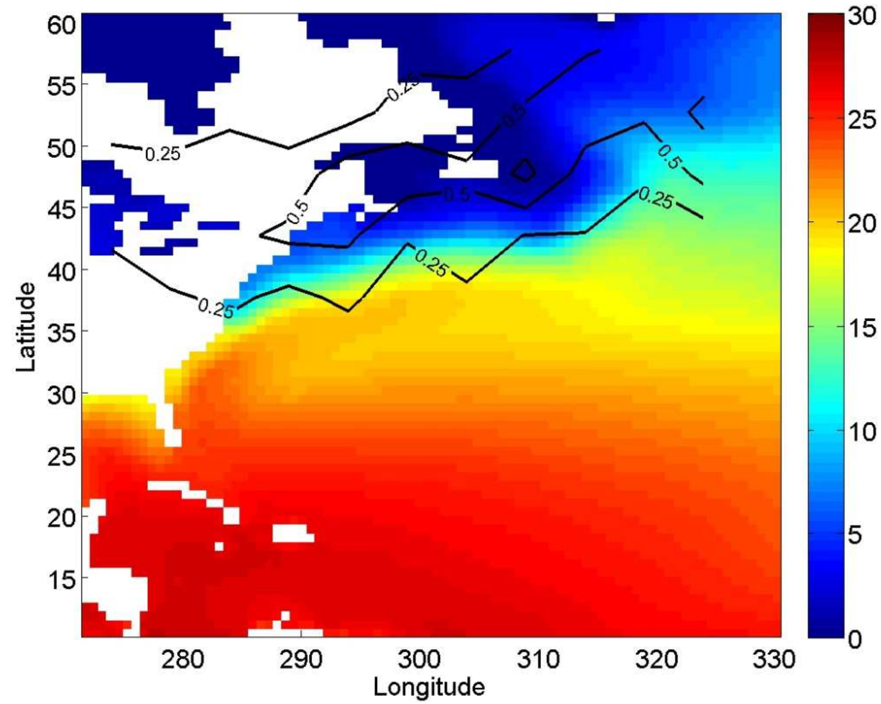
$$\rho \frac{DB}{Dt} = Q_{rad} + Q_{sen}$$

≈0 on timescales of baroclinic waves

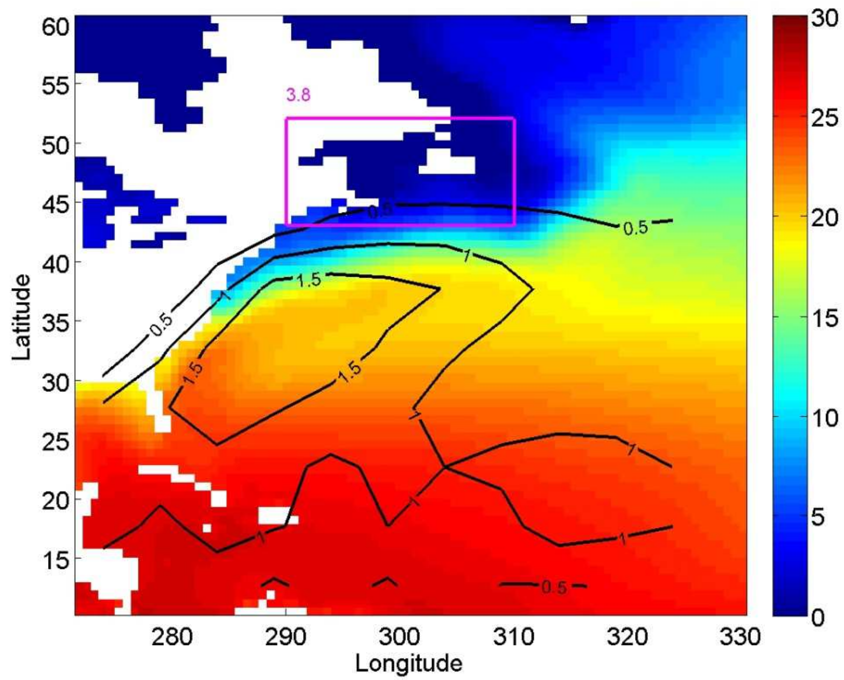
- Atmospheric application here using moist enthalpy $h = c_p T + l_v q$

KEmax events with RH>2/3

- Number of events per winter within 5 X 5 degree boxes



- Number of events with the right Bernoulli at low level ***at the same time*** (again within 5X5 degree boxes)



KEmax events with RH>2/3

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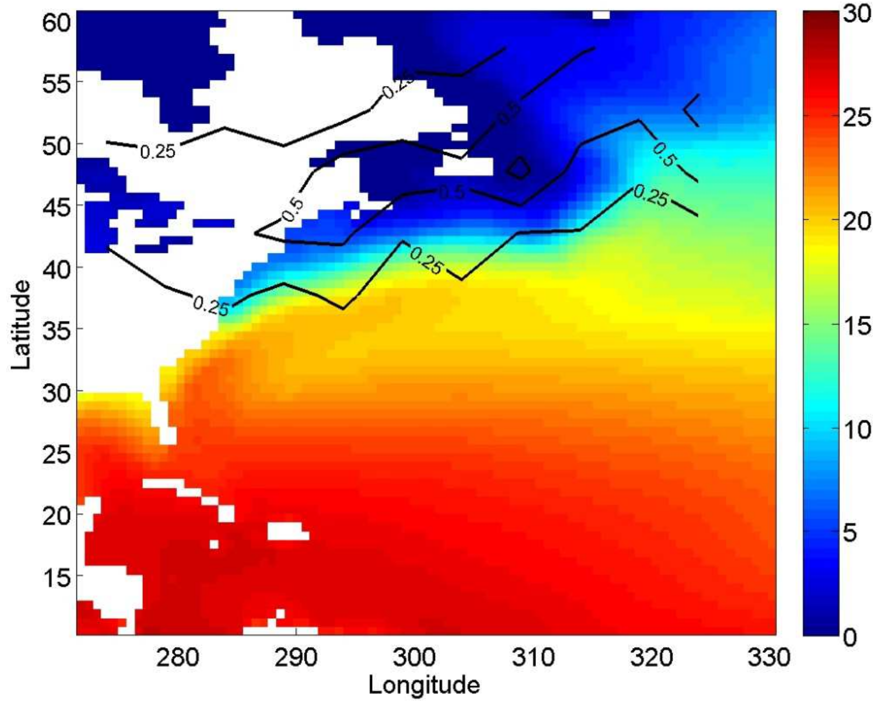
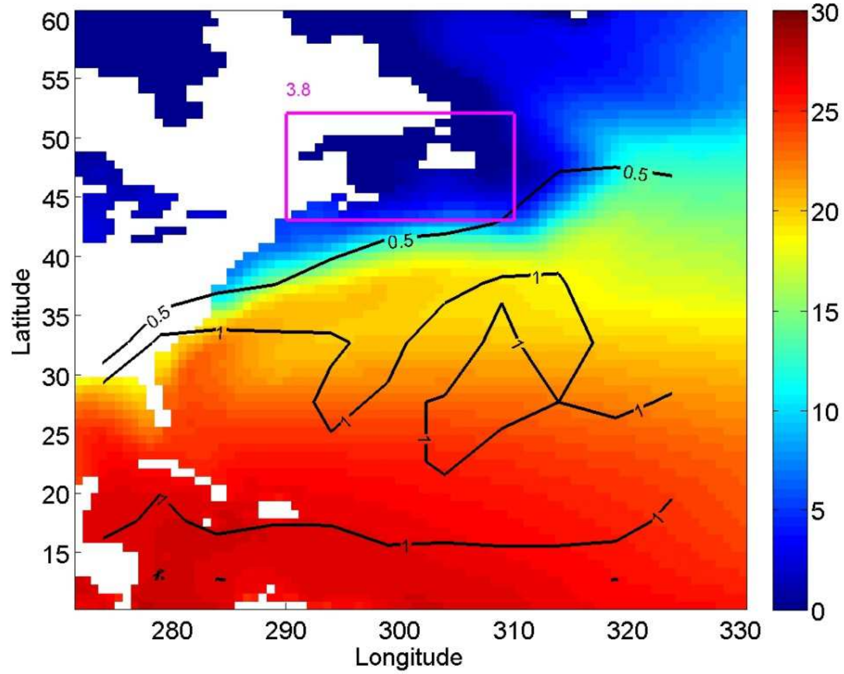


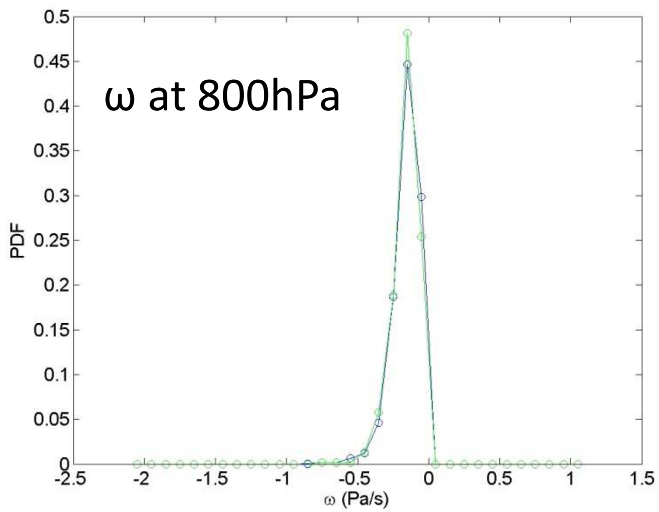
- Number of events with the right Bernoulli at low level ***two days earlier*** (again within 5X5 degree boxes)



Further properties of "moist KEmax events" at 300hPa

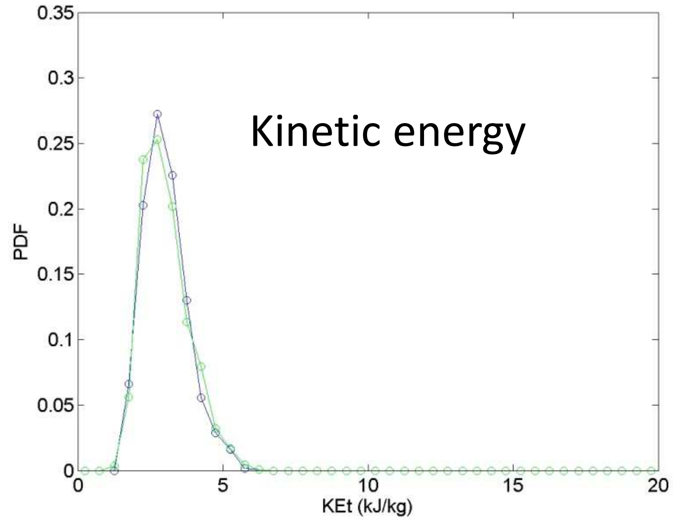
(ERAinterim, DJF 1980-2012)

- Stronger low level ascent



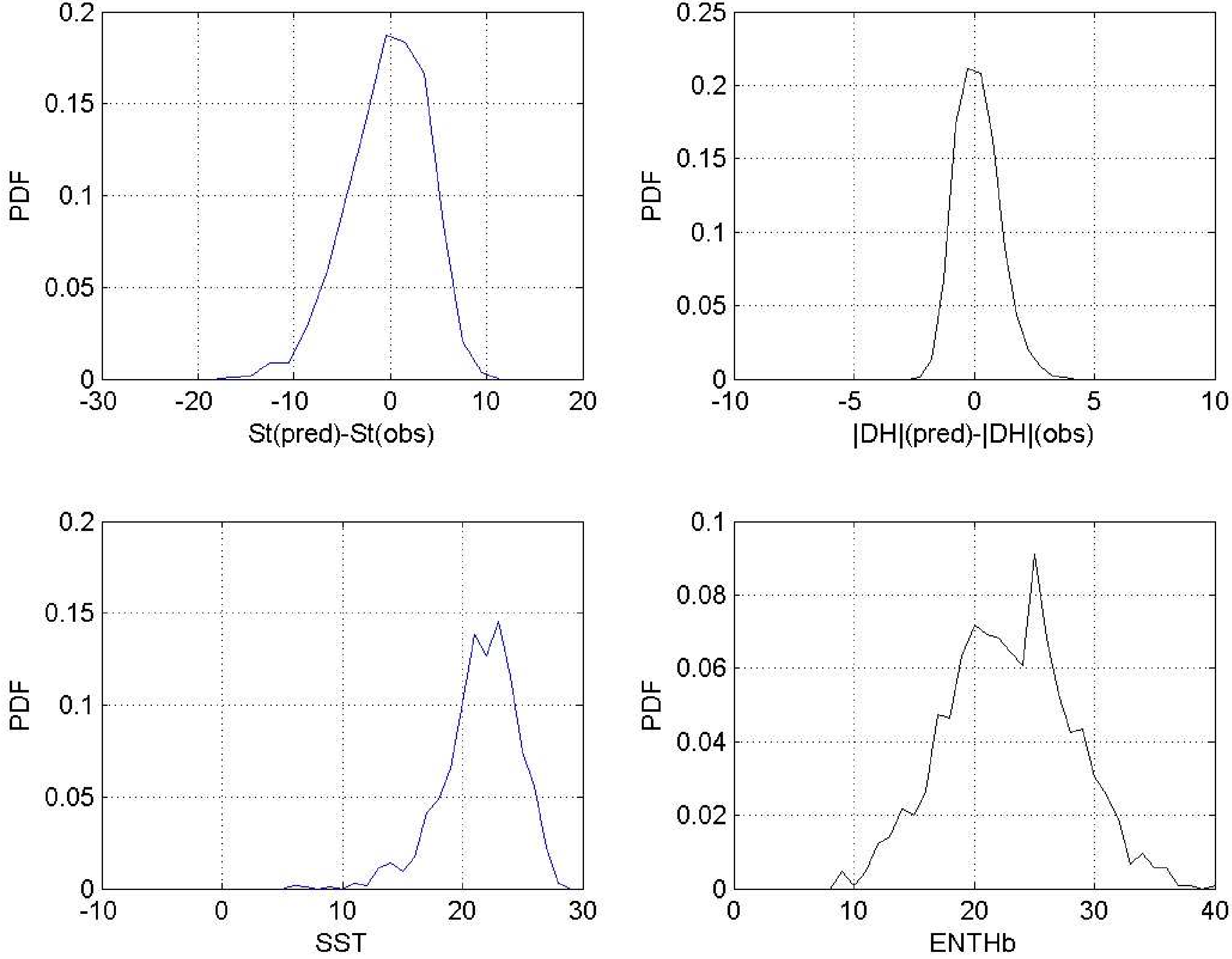
RH>0.6

RH<0.6

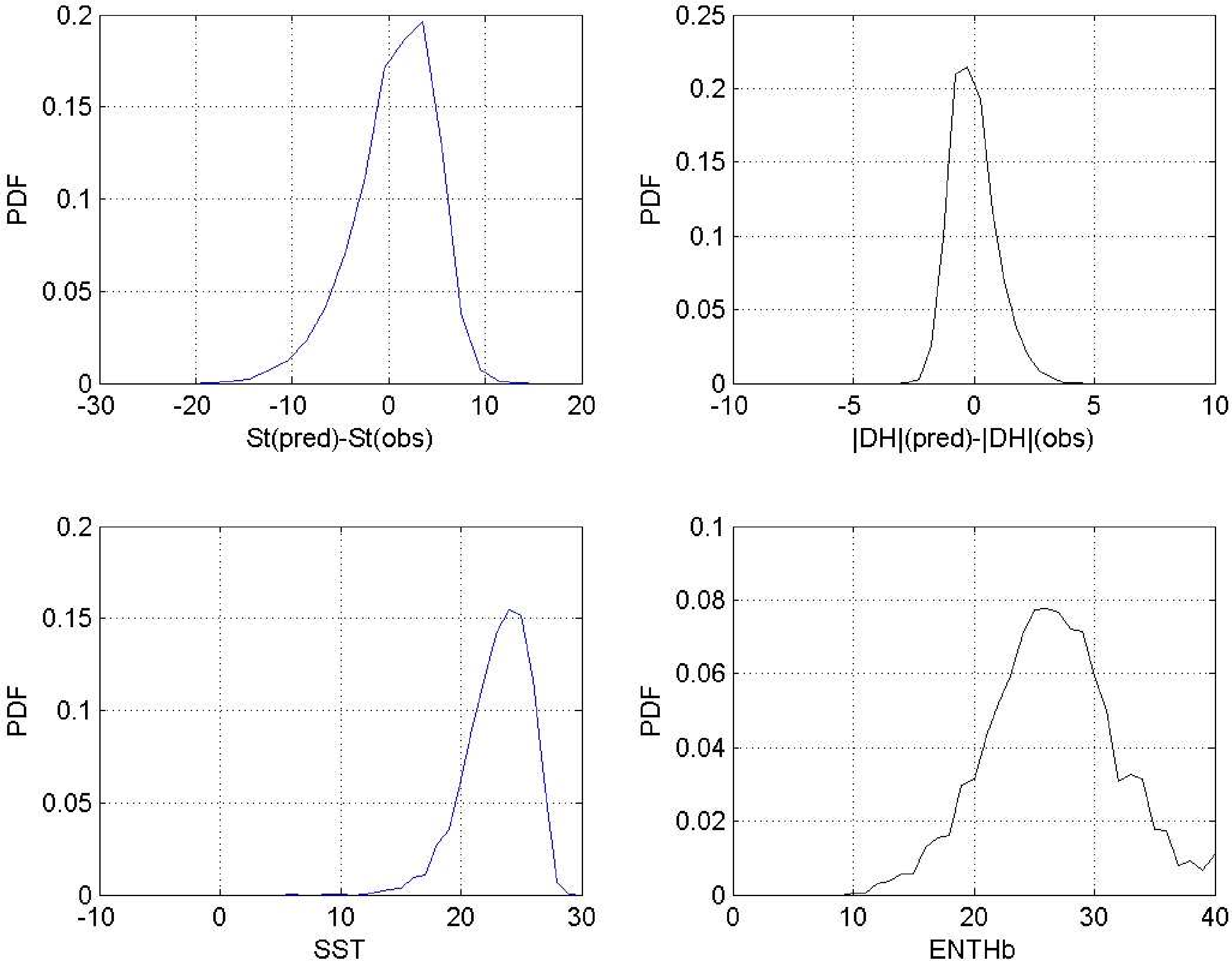


- Broader distribution of KE (not shown here).

TD model performance for KEmax with RH>0.6 (DJF, 1980-2012)

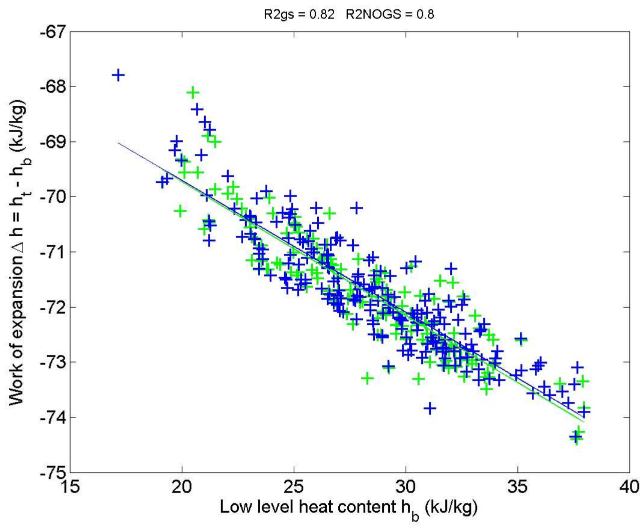


TD model performance for KEmax with RH<0.6 (DJF, 1980-2012)



The thermodynamic constraint

- At fixed relative humidity, an increase in Tb leads to a decrease in |Δh| ("divergence of the moist adiabats").
- This is more than offset by an increase in |Δh| due to increasing qb.
- Net effect is an approximate linear relationship between |Δh| and hb



$$|\Delta h| \approx \frac{\overline{\Delta T}_{ma}}{\overline{T}_b} h_b + cst$$

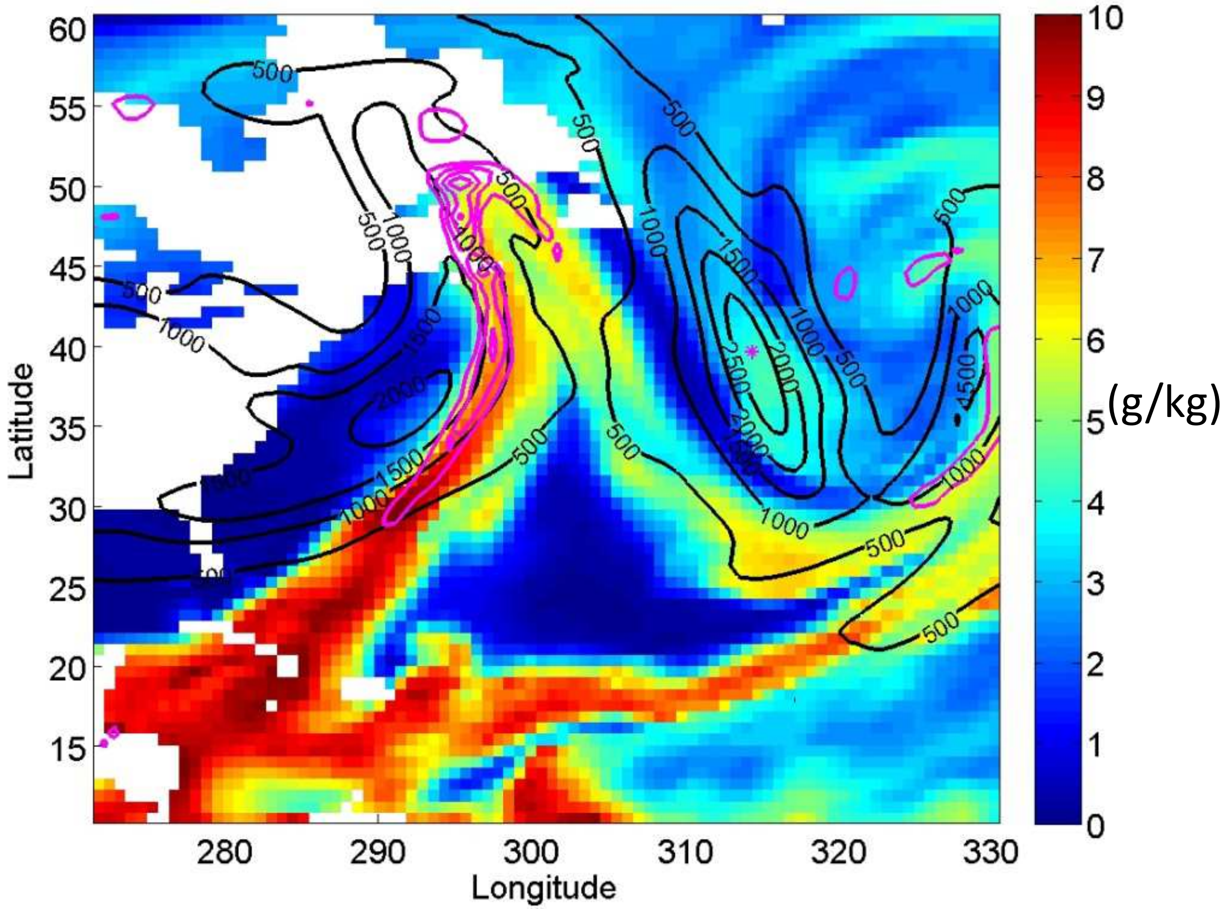
These features are readily seen in daily snapshots

Black contours:
$(U^2+V^2)/2$ at 300hPa

Color:
Specific humidity at 800hPa

Magenta:
Negative ω at 800hPa

Random snapshot from ERAint

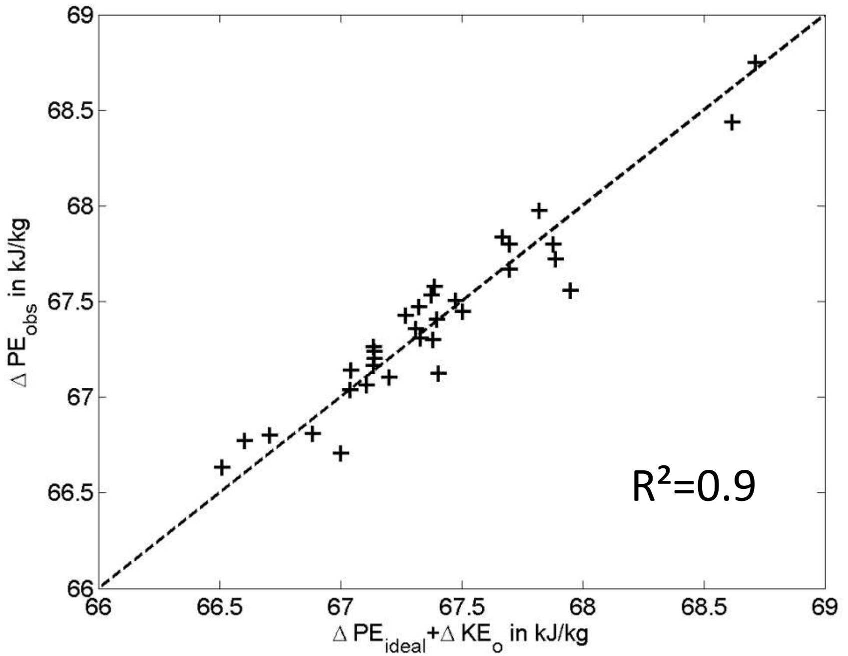


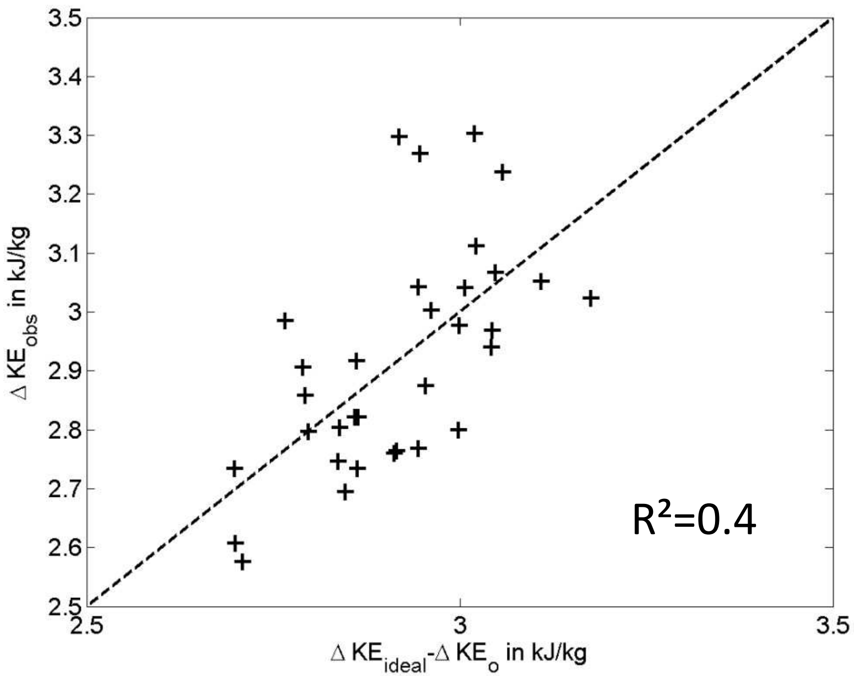
Test of the model: actual scatter plots for KEmax events with RH>2/3

$$\Delta PE \approx |\Delta h| + \Delta KE_o$$

- Good agreement considering the minimal GFD information

$$\Delta KE \approx \frac{1}{2}\left(\frac{N}{g}\right)^2 |\Delta h|^2 - \Delta KE_o$$





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