

Modulations of planetary waves by upward-propagating Rossby wave packets prior to a stratospheric sudden warming event: observations and ensemble forecasts.

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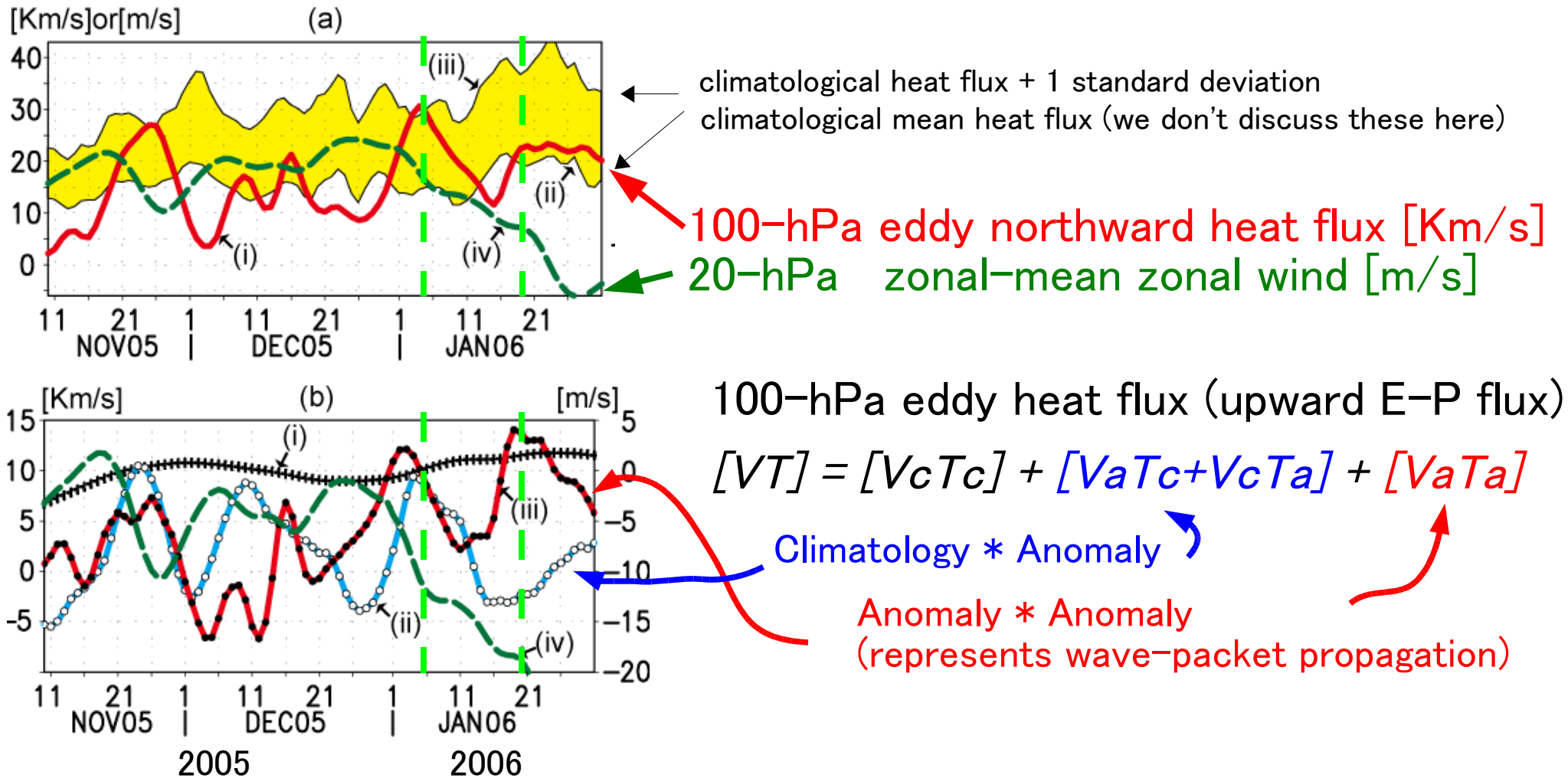
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- Aim of this study
  - Amplification mechanism of the upward planetary wave before the sudden warming event in January 2006.
  - Detection of initial errors that caused large uncertainty in the prediction of the sudden warming by using ensemble forecast produced by Japan Meteorological Agency (JMA)

### Conclusion

Initial value errors around a tropospheric cyclone might make it difficult to predict the sudden warming

# Weakening of the polar-night jet and upward propagating planetary waves in 2005/6 winter

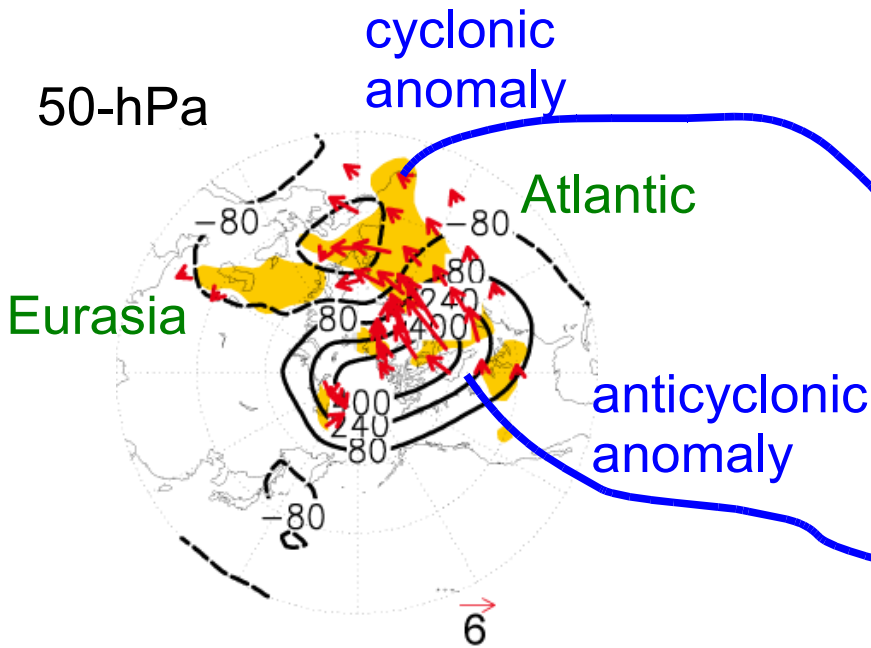


Climatology-anomaly interaction term contributed to VT only at the beginning of January

Anomaly-anomaly interaction term (i.e. wave-packet propagation) contributed to VT both at the beginning and middle of January

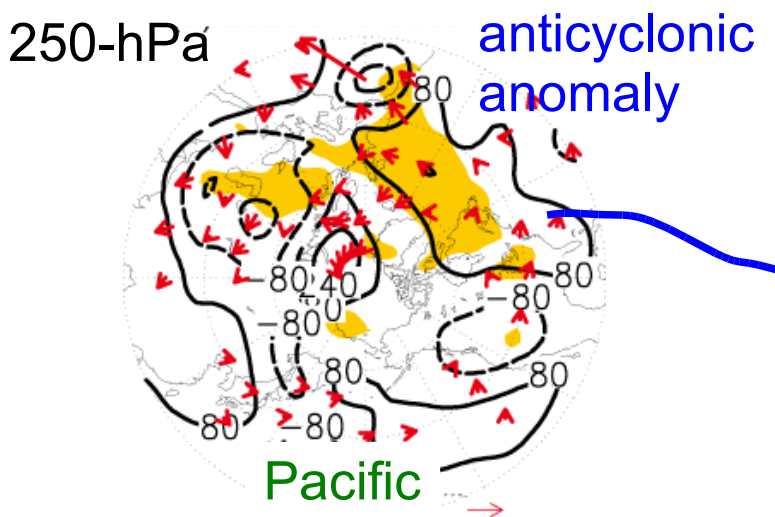
Wave-packet propagation in middle January is discussed →

# Origin of Upward wave-packet propagation (16–20 Jan)

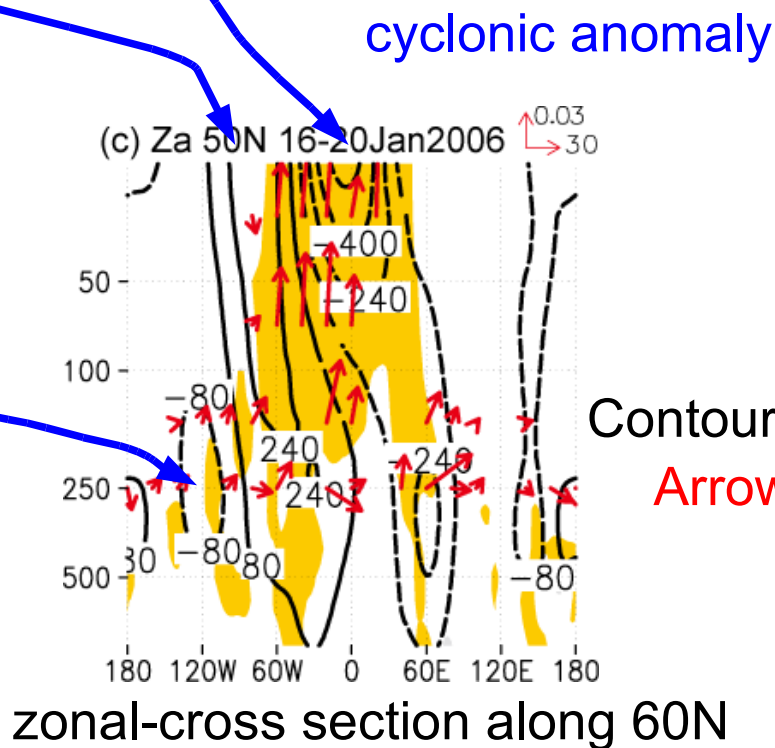


“Wave packet” emanated from anticyclonic anomaly over the Atlantic.

Then formed anticyclonic and cyclonic anomaly in the stratosphere



(100-hPa) upward T-N flux



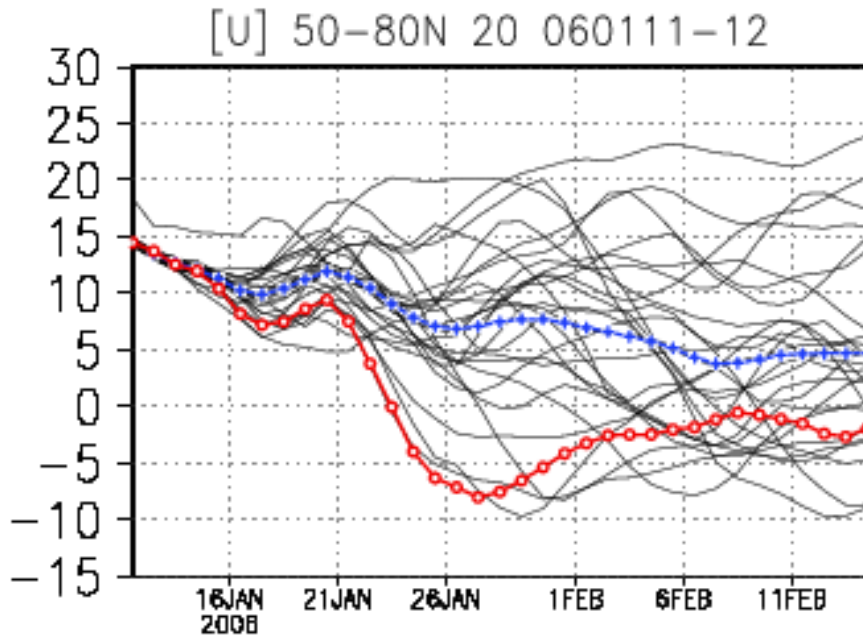
# Summary so far

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- The stratospheric sudden warming observed in middle January was due to upward waves from the troposphere.
- The upward wave events at the beginning and middle of January were particularly strong.
- The first one was contributed to by anomaly–anomaly interaction term (i. e. wave packet propagation) and also by anomaly–climatology interaction term.
- The latter was contributed to only by wave–packet propagation, which was emanated from the anticyclonic anomaly over the Atlantic Ocean.
- The anomaly over the Atlantic Ocean was developed by enhanced stormtrack activity, which was associated with downstream development from the Pacific (not shown).

# Japan Meteorological Agency (JMA) 1-month ensemble forecast

## 20-hPa zonal-mean zonal wind



16Jan

1Feb

Each ensemble member  
ensemble average  
Reanalysis (JRA25)

## JMA 1-month ensemble forecast

- Resolution; T106, up to 0.4hPa
- Initial perturbations are made by combination of Lagged Averaging forecast (LAF) and Breeding of Growing mode (BGM)
- Forecast is run separately on every Wednesday and Thursday due to LAF (13 members for each day).
- Forecast product started from 11 and 12 January 2006 is used.
- (The system was updated to TL159 in March 2006 and the member was increased to 50.)



JMA's character Harerun

# Development of Spread of height at 250-hPa level

Spread = variance of ensemble members

12Jan

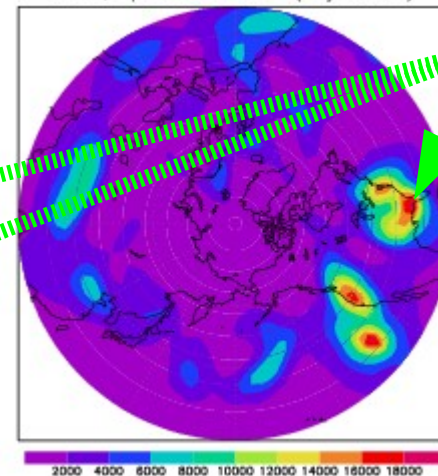
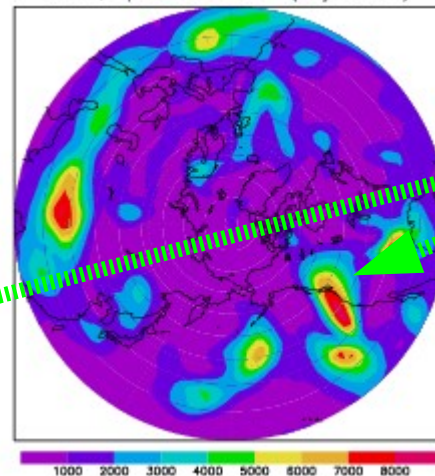
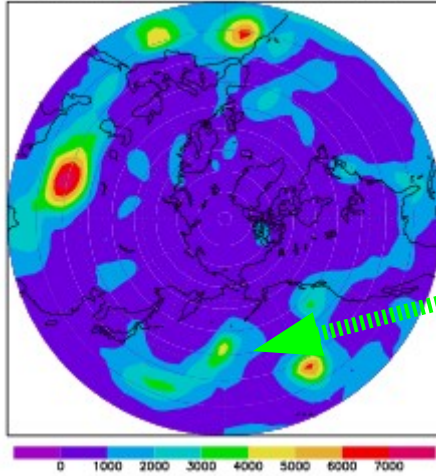
13Jan

14Jan

z250, spread 060111 (12jan2006)

z250, spread 060111 (13jan2006)

z250, spread 060111 (14jan2006)



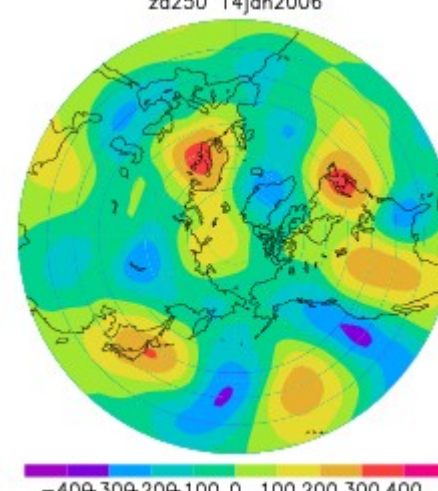
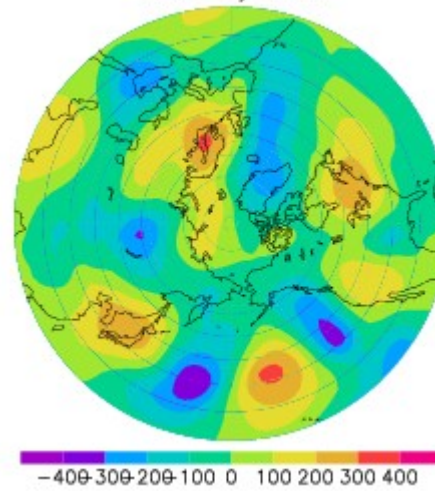
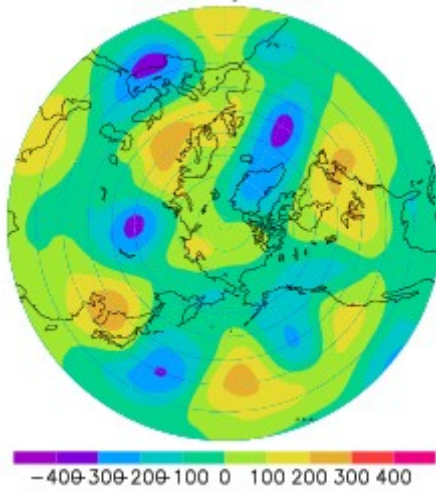
Max of spread

spread

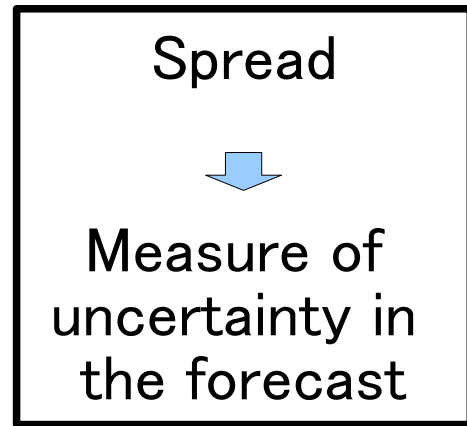
za250 12jan2006

za250 13jan2006

za250 14jan2006



height anomaly  
(NCEP)

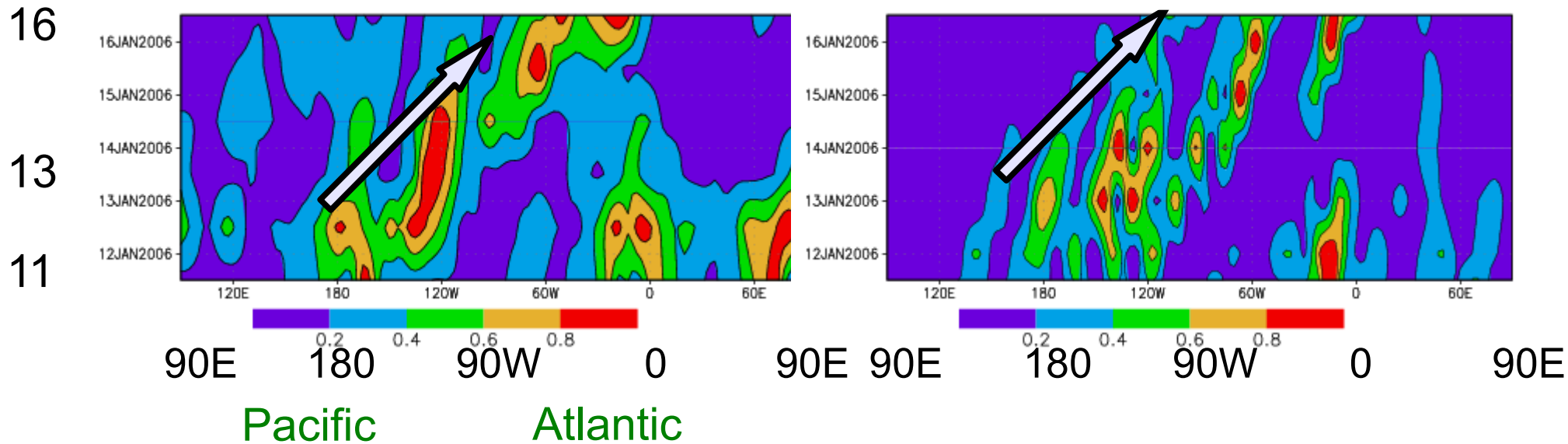


# Time evolution of spread

1. Averaging 250 hPa spread between 20-60N.
2. Normalized by maximum values along longitude in each day.

Initial day; 11 Jan

NCEP  $V^2$

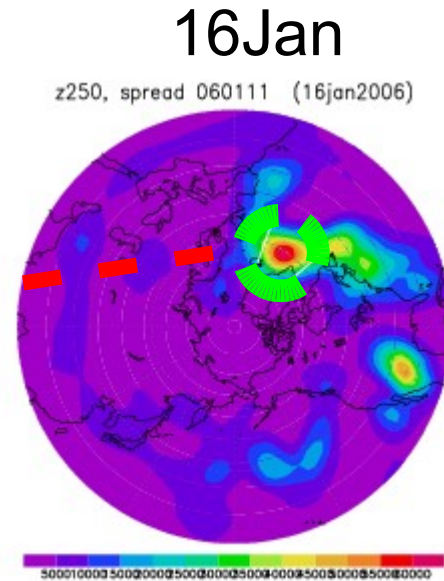
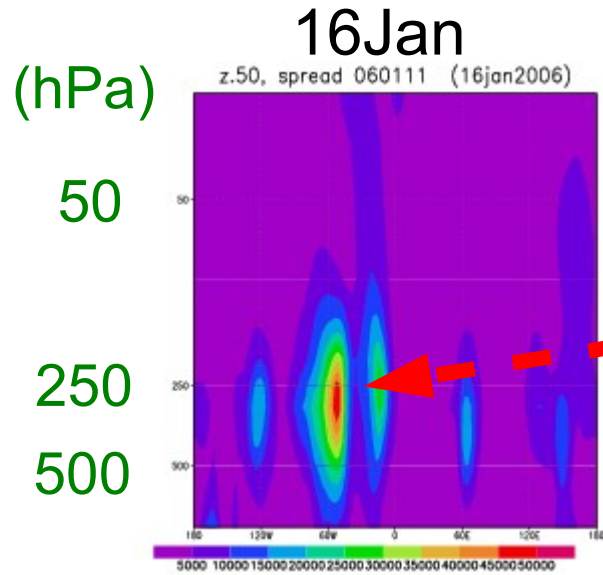


“phase speed” = 5m/s ~ 6deg/day      phase speed = 7m/s ~ 9deg/day  
“group velocity” = 28m/s ~ 36deg/day      group velocity = 25m/s ~ 33deg/day

Propagation of spread maximum corresponds to group velocity propagation of “downstream development” observed in the reanalysis data.  
Inconsistency of downstream development predictions among ensemble members leads to eastward movement of the spread maximum.

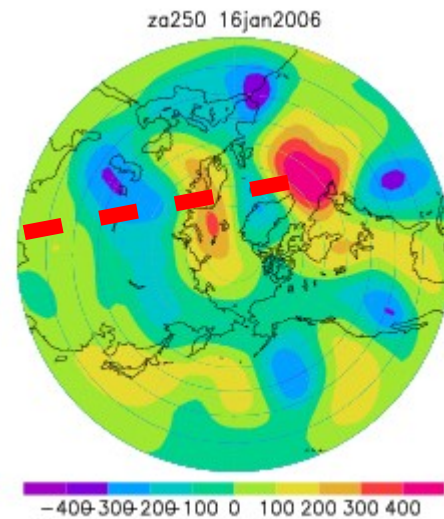
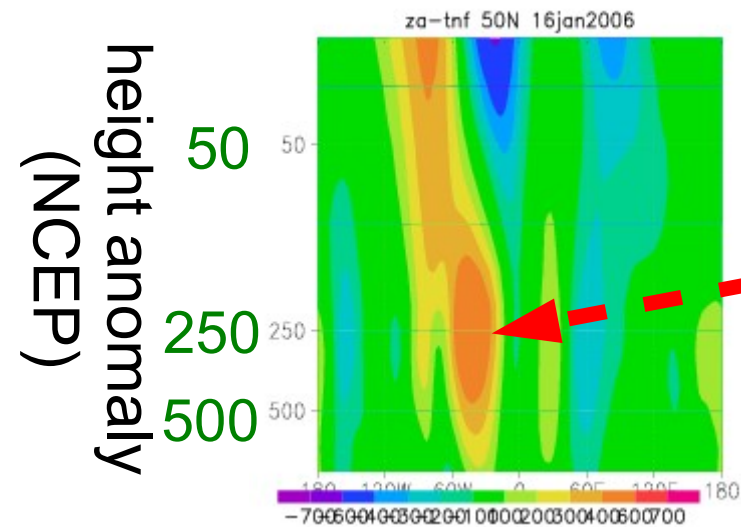


# Extension of spread into the stratosphere (50 N latitude)



Spread maximum was found around the anticyclonic anomaly over the Atlantic.

Spread maximum was confined almost to the troposphere on this day.



Atlantic

# Extension of spread into the stratosphere (50 N latitude)

16Jan

17Jan

18Jan

(hPa)

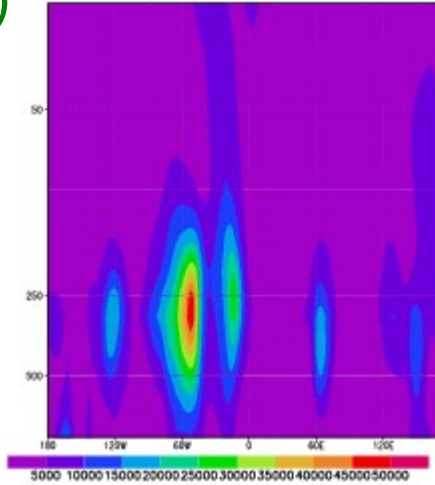
spread

50

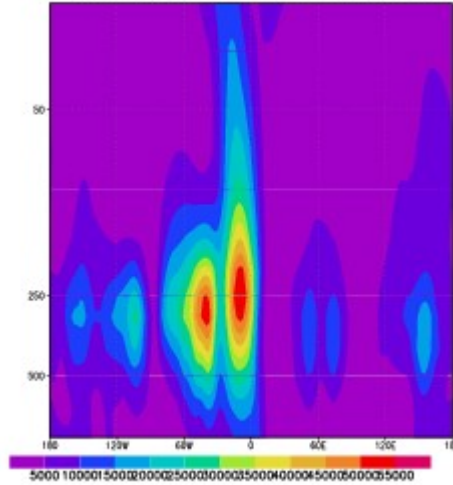
250

500

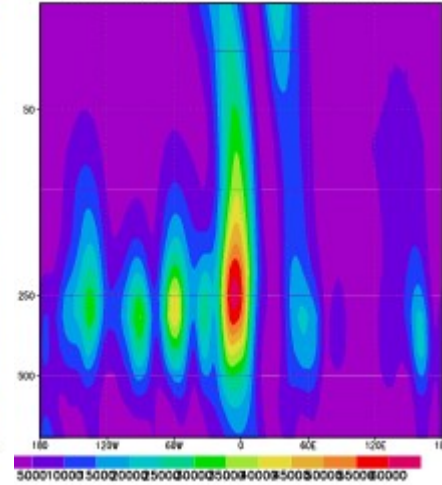
z.50, spread 060111 (16jan2006)



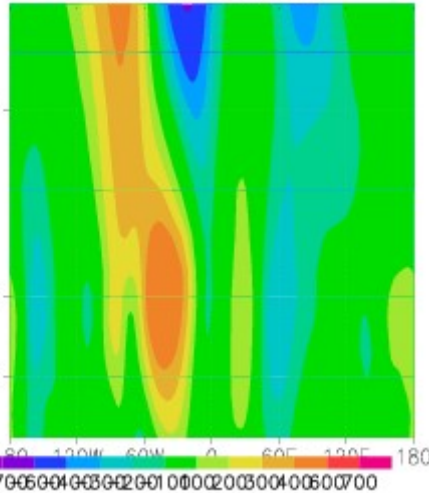
z.50, spread 060111 (17jan2006)



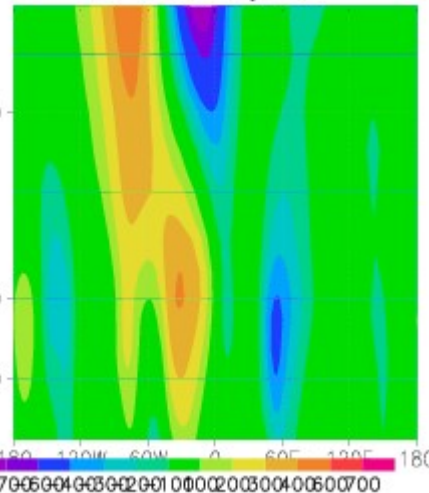
z.50, spread 060111 (18jan2006)



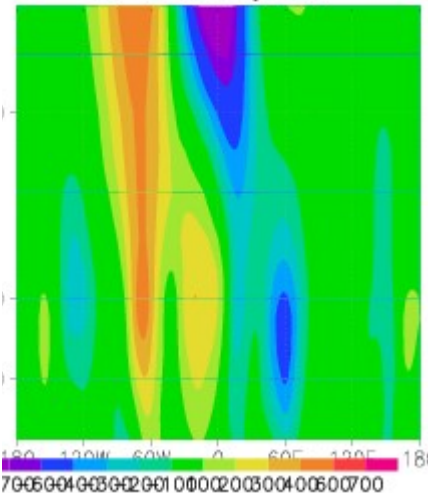
za-tnf 50N 16jan2006



za-tnf 50N 17jan2006



za-tnf 50N 18jan2006



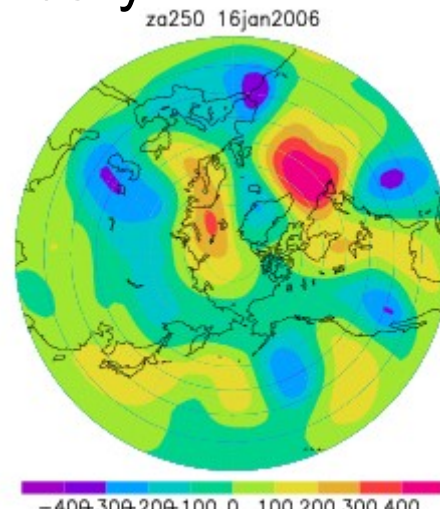
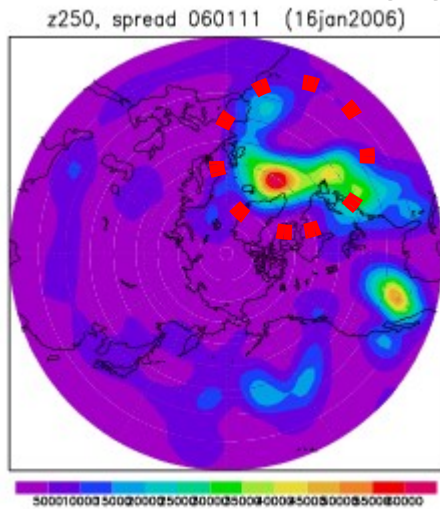
Associated with wave-packet propagation, spread maximum extended to the stratosphere, due to inconsistency of prediction of wave-packet propagation among members

This might lead uncertainty of SSW prediction.

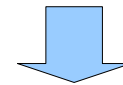
Atlantic

# Simple Sensitivity Analysis (Enomoto et al. 2007)

16 January



What kind of initial perturbations made large spread (i.e. uncertainty) over the Atlantic on 16 January?



Simple Sensitivity Analysis

Spread of z250    Anomaly of z250

Simple sensitivity analysis is useful in detecting most influential (sensitive) region in the initial value field, for the forecasting of particular region on particular day (verification region) by using ensemble forecast members.

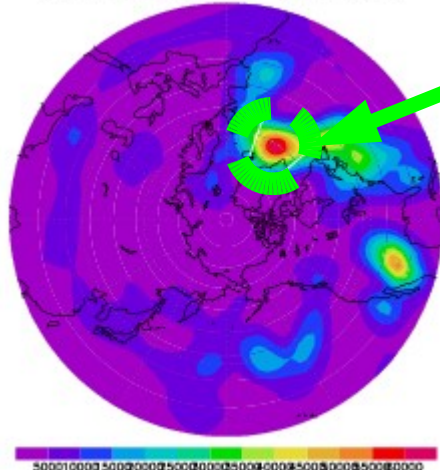
Unlike usual sensitivity analysis, the tangent linear model of the forecast model is not necessary.

# For the Atlantic anticyclonic anomaly on 16 January

16 January

z250, spread 060111 (16jan2006)

spread

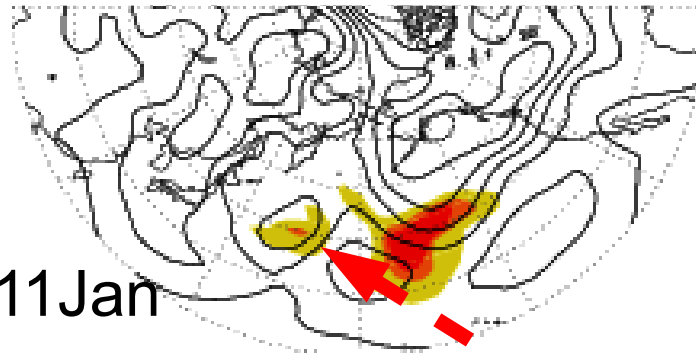


Verification region ; On 16Jan, z250 spread Maximum region (310-340E,50-65N,1000-100hPa)

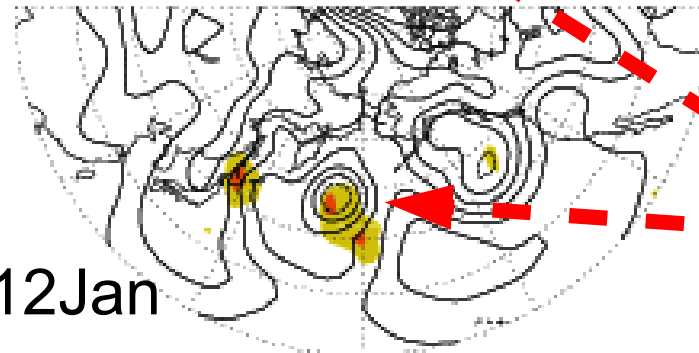
initial day; 11, 12 Jan each day

Contour; SLP(NCEP)  
Shading; Large sensitivity as total energy

11Jan



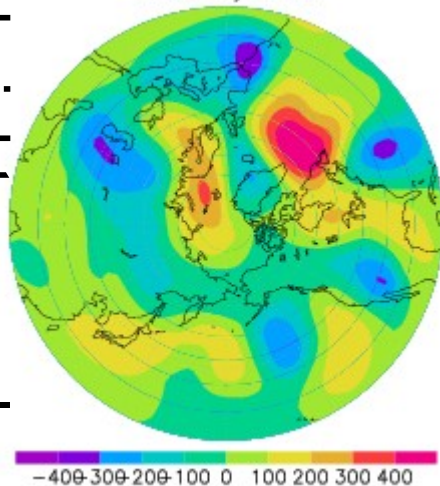
12Jan



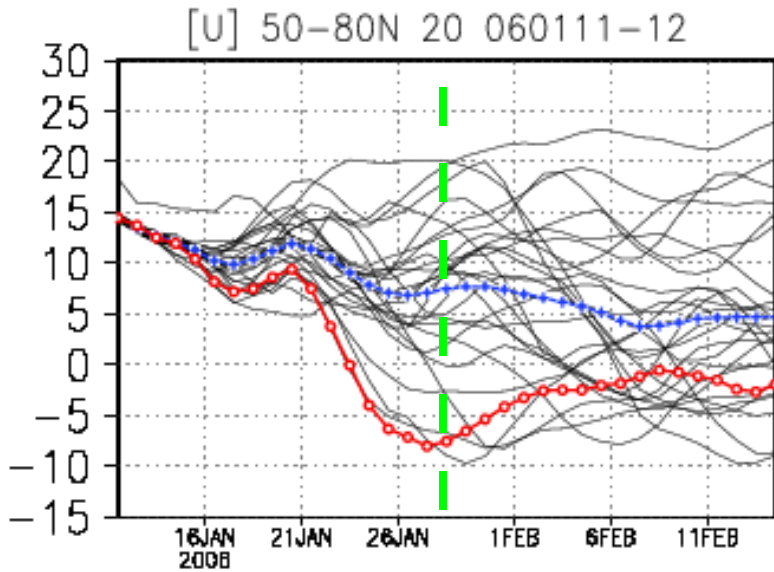
Prominent over the Pacific  
Corresponding to abrupt development of a surface cyclone<sup>1,2</sup>

height anomaly (NCEP)

za250 16jan2006



# Sensitivity analysis for the polar vortex

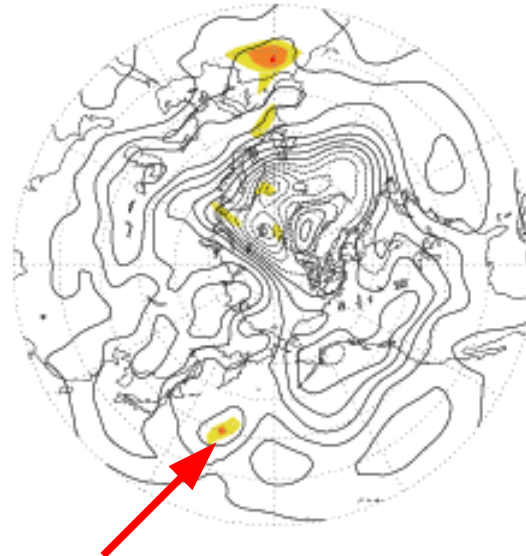


Verification region ; 28Jan,  
stratospheric polar vortex  
(0-360E,50-90N,70-10hPa)

initial day; 11, 12jan

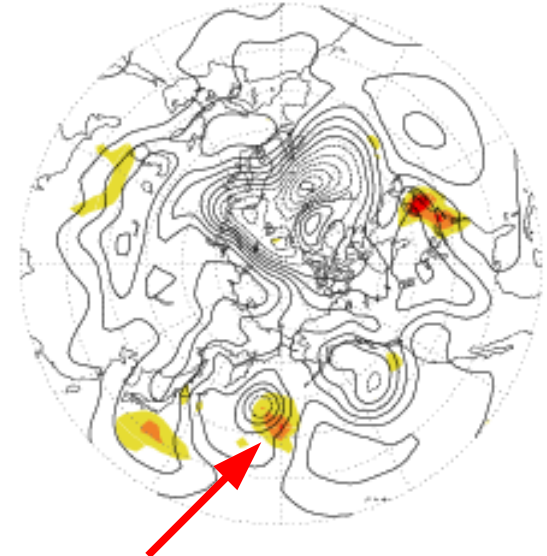
11Jan

sum 20060111->20060128



12Jan

sum 20060112->20060128

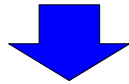


Prominent over the  
Pacific in both days

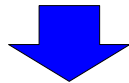
# Conclusion for analysis of ensemble forecast

## Reanalysis data

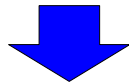
A developing cyclone  
over the Pacific



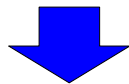
Downstream development from  
the Pacific to the Atlantic



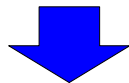
Enhancement of  
stormtrack activity over



Development of  
anticyclonic anomaly over



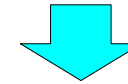
Upward wave-packet propagation  
into the stratosphere



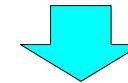
The sudden warming

## Ensemble forecast

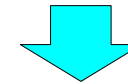
Initial value errors around a  
developing cyclone over the



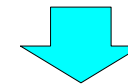
Uncertainty in prediction (UP) of  
downstream development from the  
Pacific to the Atlantic



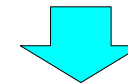
UP of stormtrack activity  
over the Atlantic



UP of development of anticyclonic  
anomaly over the Atlantic



UP of upward wave-packet  
propagation into the stratosphere



UP of the sudden warming <sup>14</sup>