The influence of low-frequency variability on the life cycles of high-impact weather during the winters of 2009-2011: simulations, predictions and observations

Mel Shapiro; Joseph Tribbia; Thomas Galarneau; Julio Bacmeister; Alan Norton

National Center for Atmospheric Research, Boulder CO USA

Ryan Maue; Rolf Langland

Naval Research Laboratory, Monterey CA USA

World Climate Research Program (WCRP) Open Science Conference 2011
Denver CO, 24-28 October 2011

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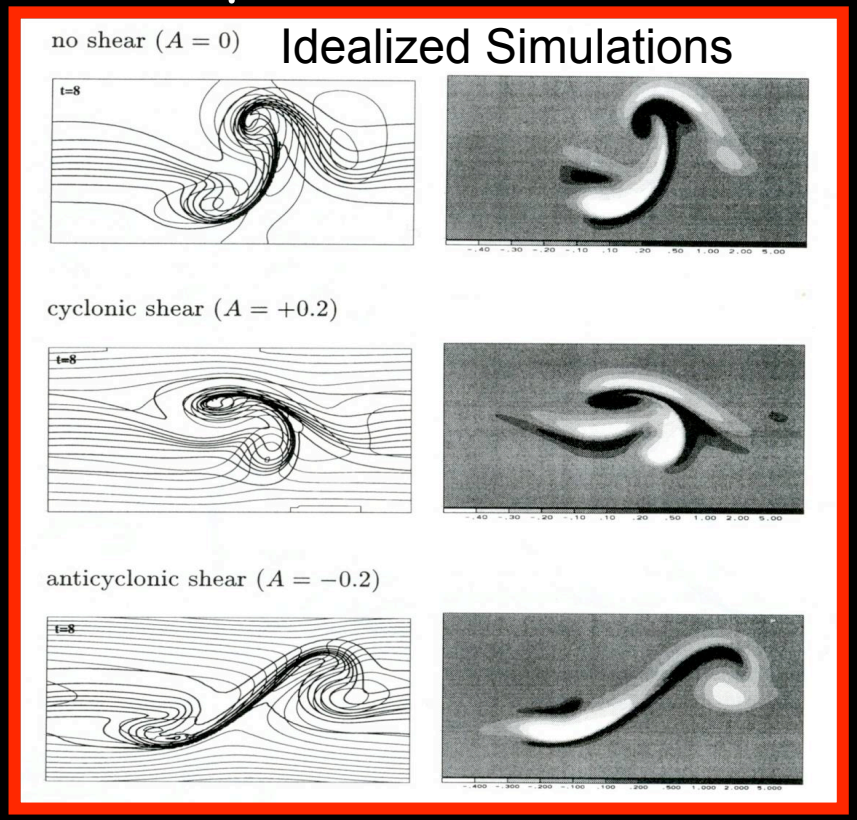

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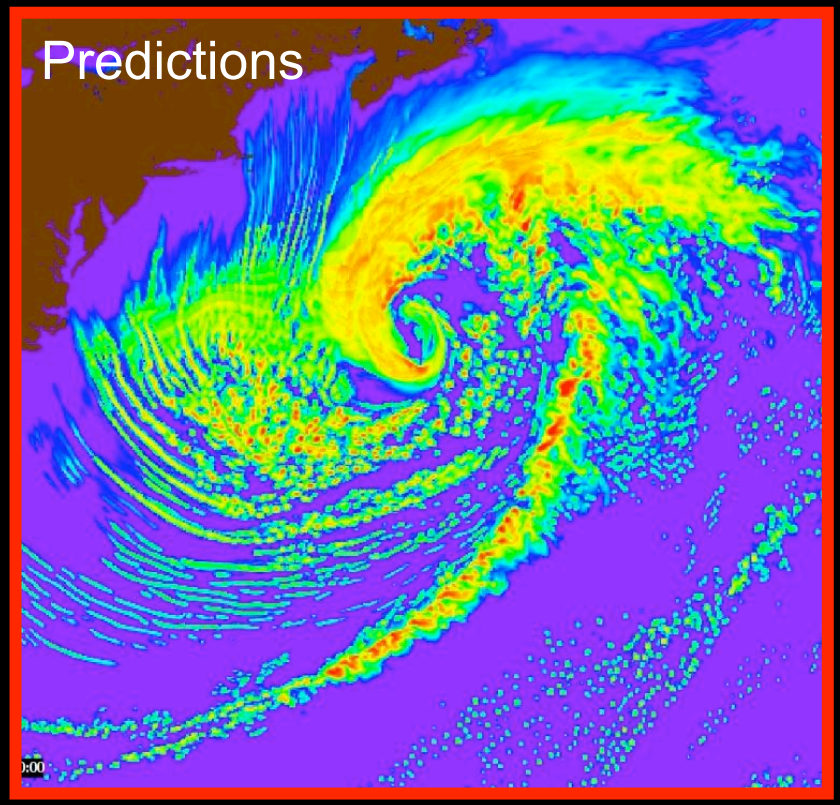

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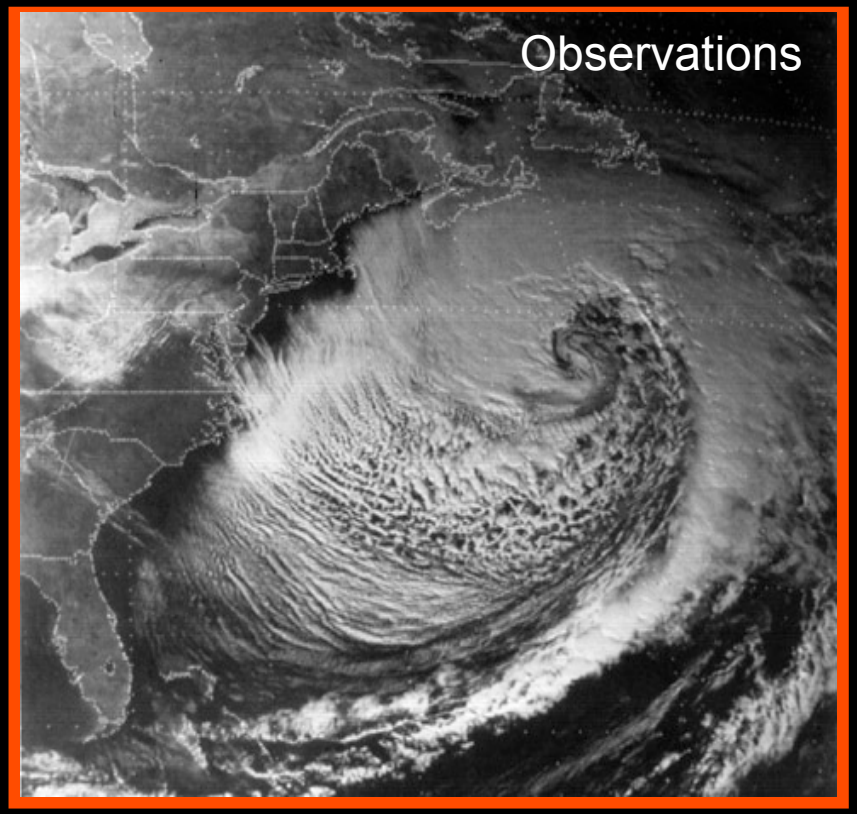

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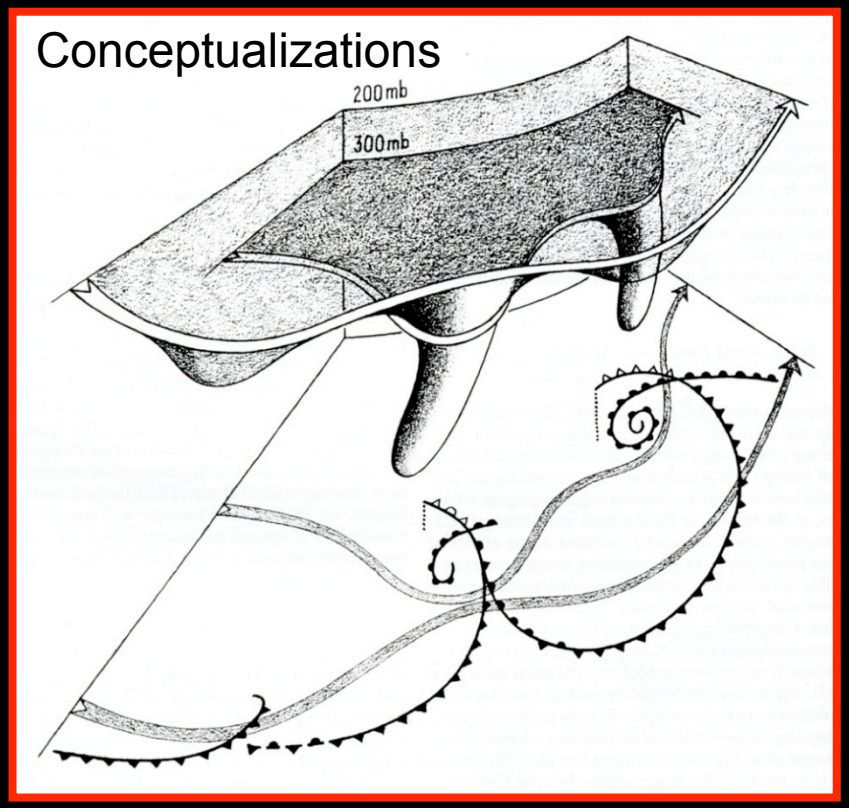

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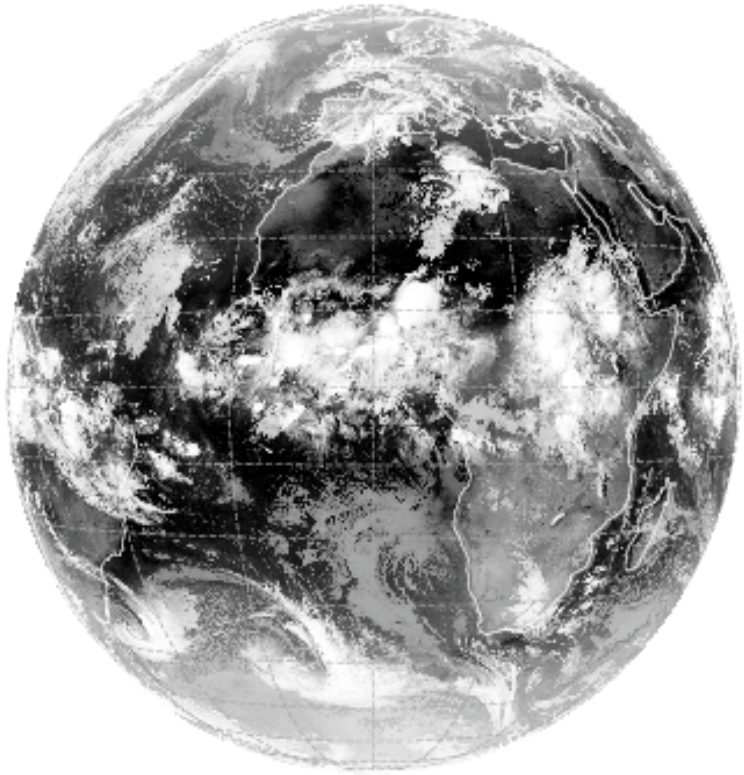
In Search of Seamless Prediction

- Seamless in **Spatial Dimension** extending from highly localized cloud systems to global circulations and their two-way interactive feedbacks
- Seamless across **Time** spanning minutes to centuries, e.g., micro/meso-scale life cycles to long-term climate variability and change
- Seamless across **Scientific Disciplines** e.g., weather, climate, Earth-system, and socioeconomics
- Seamless across **Academia, Government Research and Service Agencies, Private-Enterprise Providers, and Hazard Risk-Reduction and Adaptation Agencies**

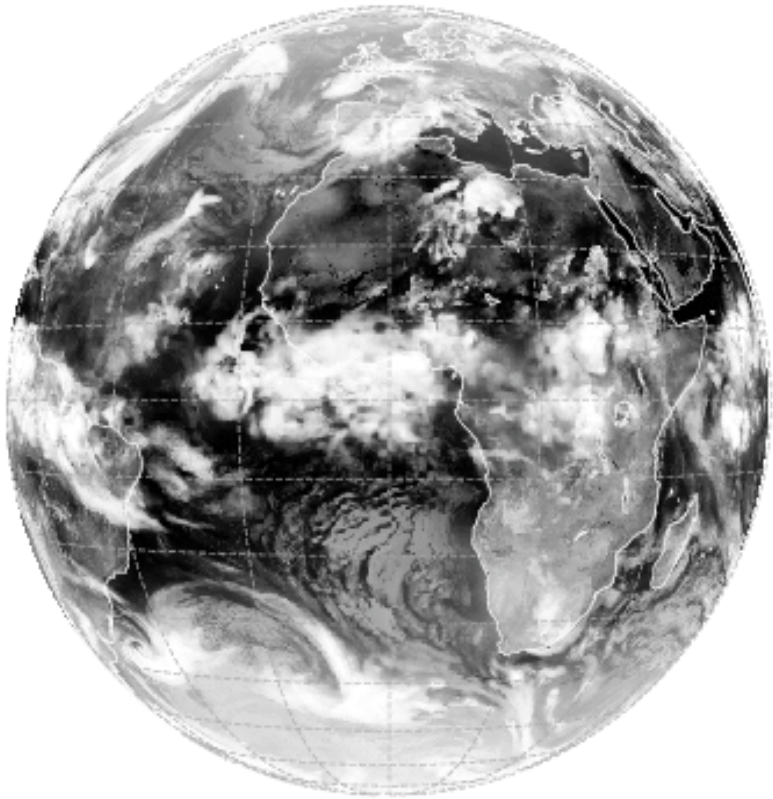
Operational Weather Prediction (T1279, ~15 km) compared with Satellite Observations

ECMWF predictions and MeteoSat observations

Meteosat 9 IR10.8 20080525 0 UTC

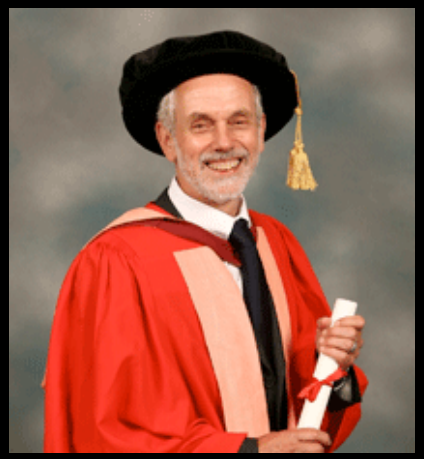


ECMWF Fc 20080525 00 UTC+0h:



The influence of planetary barotropic shear on idealized extratropical baroclinic life cycles

Adrian Simmons



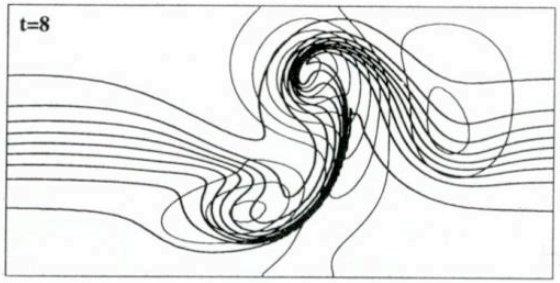
Brian Hoskins

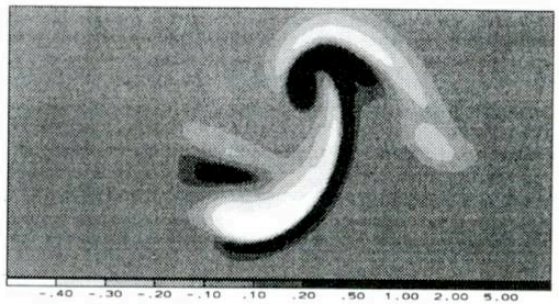
Huw Davies

Heini Wernli

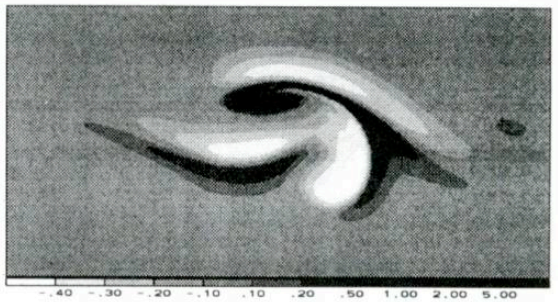
John Methven

no shear $(A = 0)$ **Life Cycle 1 (LC1)**

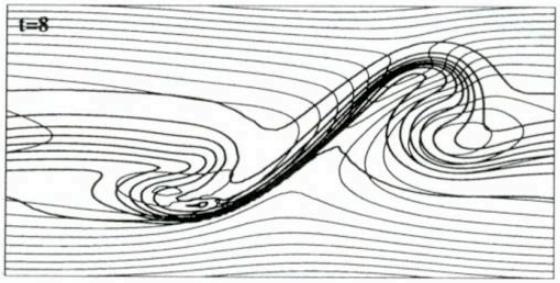


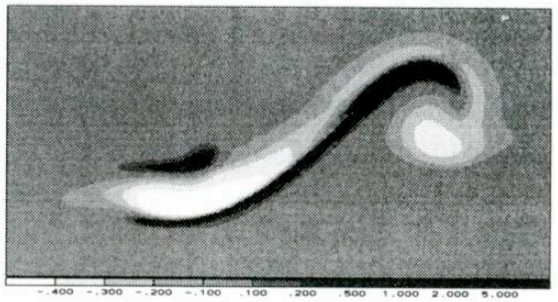


cyclonic shear $(A = +0.2)$ **LC2**



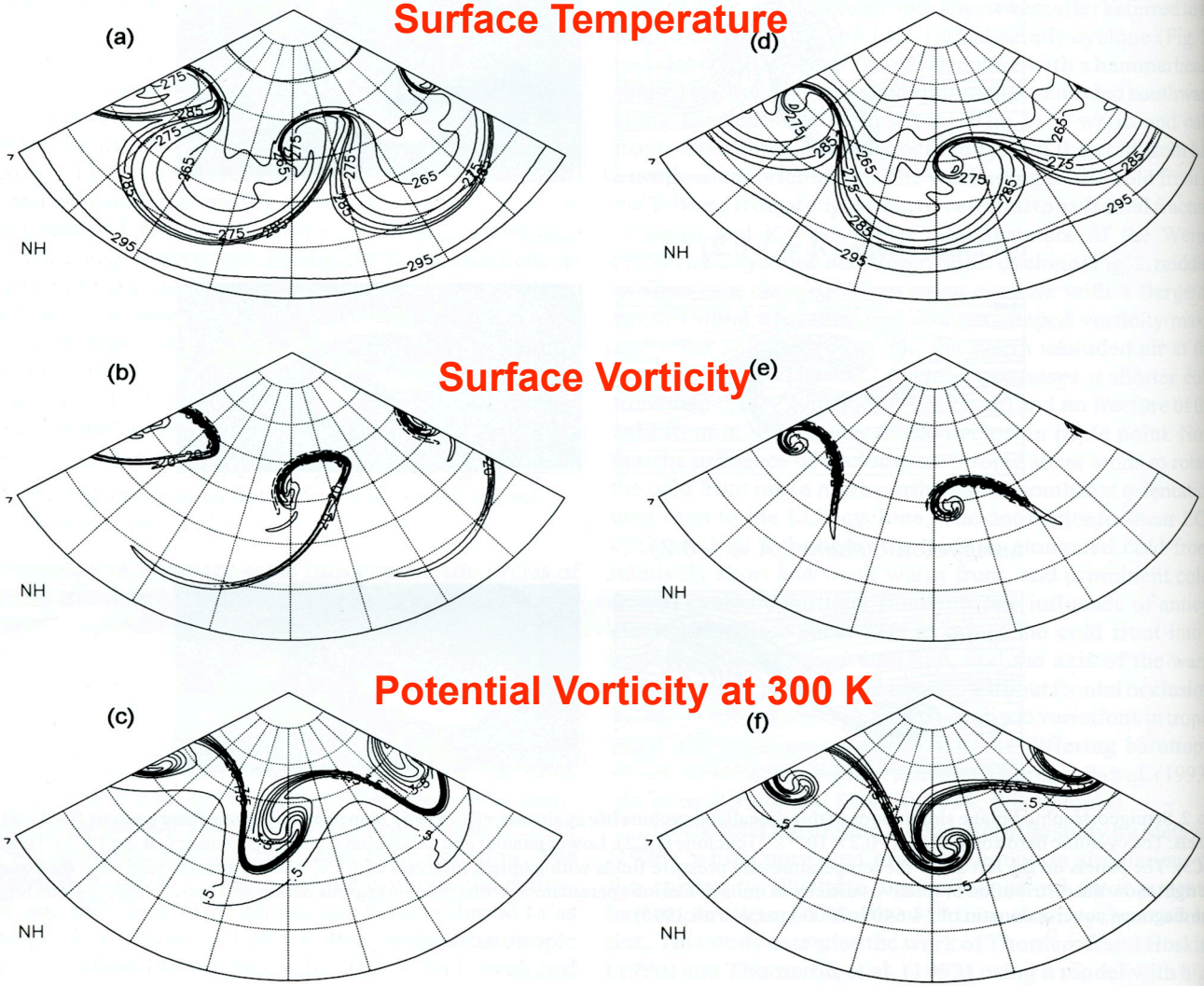
anticyclonic shear $(A = -0.2)$ **LC3**





LC1 LC2

Surface Temperature



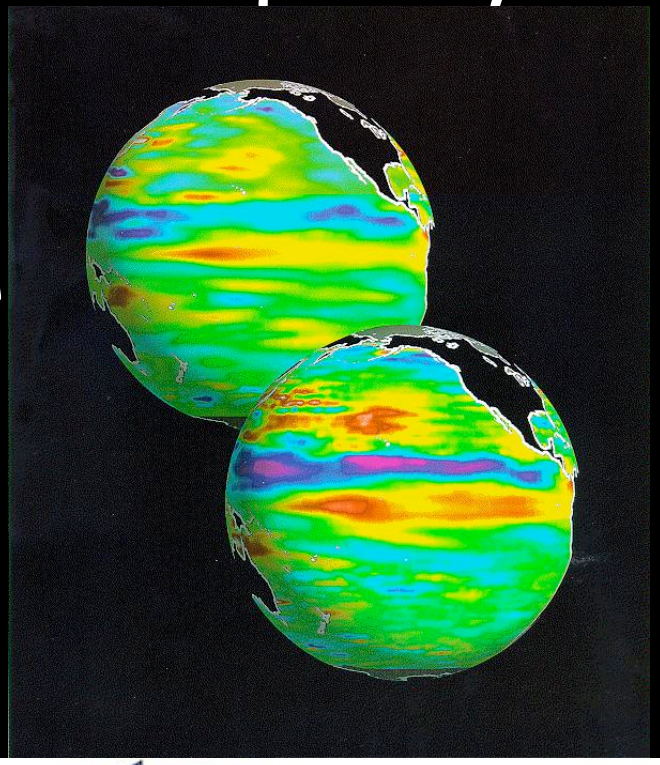
Surface Vorticity

Potential Vorticity at 300 K

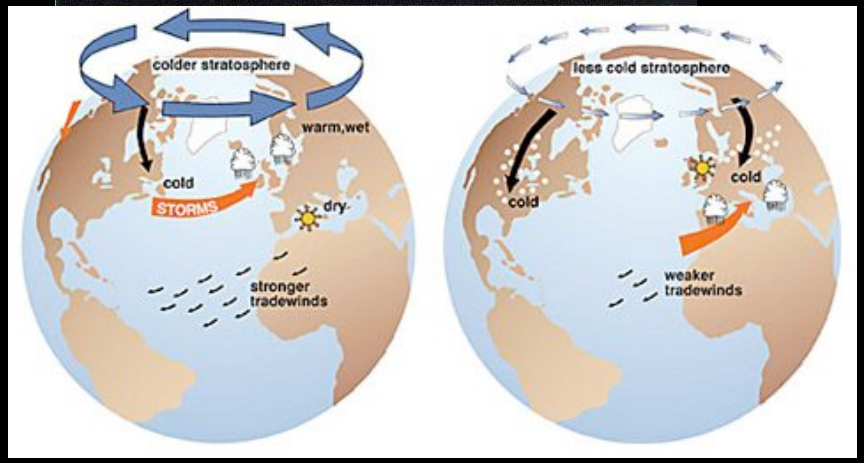
FIG. 3. Primitive-equation, spherical-domain simulations of two idealized cyclone life cycles at ~day 6. Left panels (a–c): The nonshear cyclone (LC1). Right panels (d–f): The cyclonic barotropic-shear (~0.2×10^{-4} s^{-1}) cyclone (LC2). Upper panels (a, d): Surface potential temperature at 5-K intervals. Middle panels (b, e): Surface relative vorticity at 10^{-4} s^{-1} intervals. Lower panels (c, f): Potential vorticity on the 300-K isentropic surface at 0.5-PVU intervals (Methven 1996).

The influence of low-frequency variability

El Nino Southern Oscillation

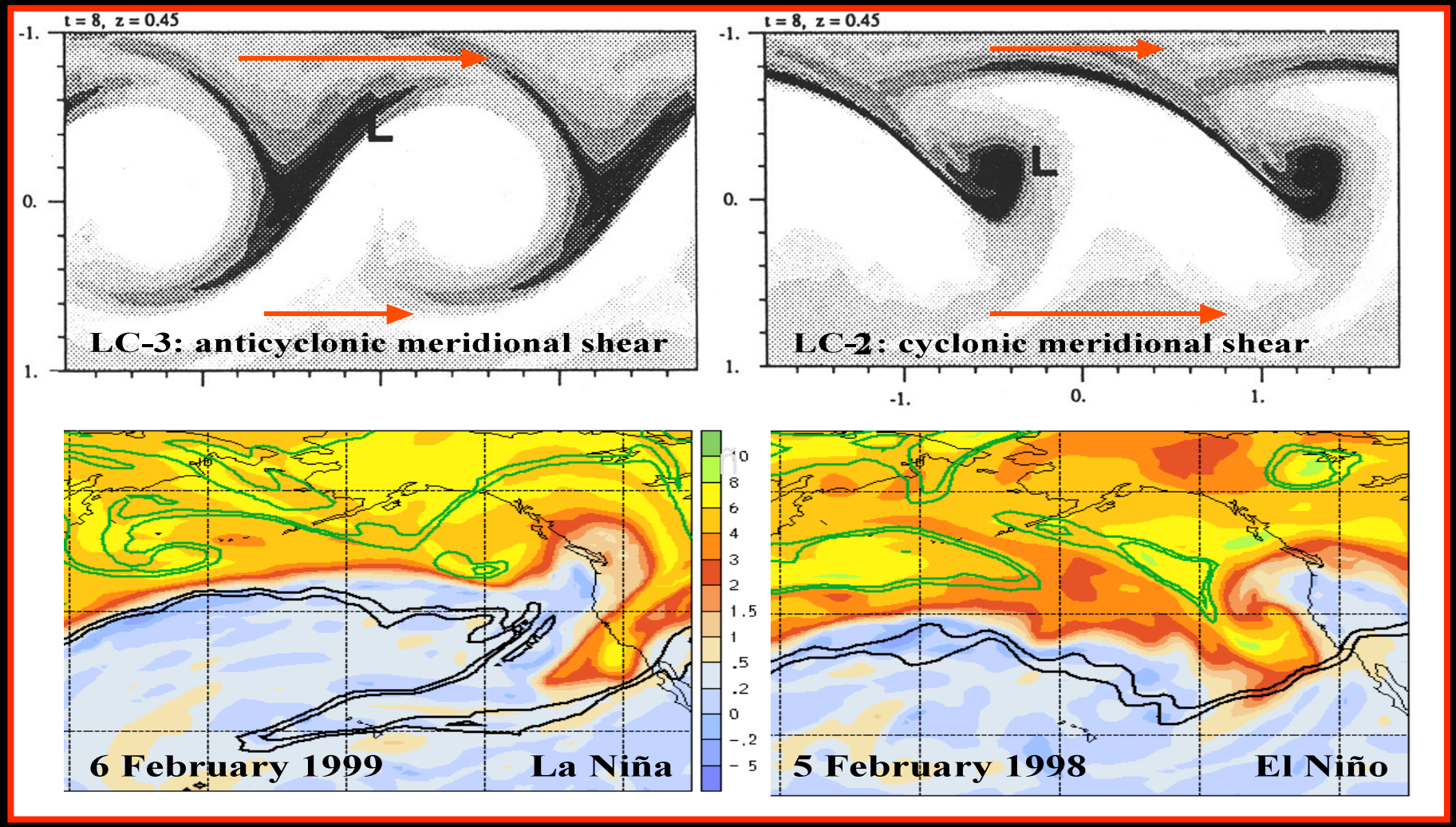


Arctic Oscillation



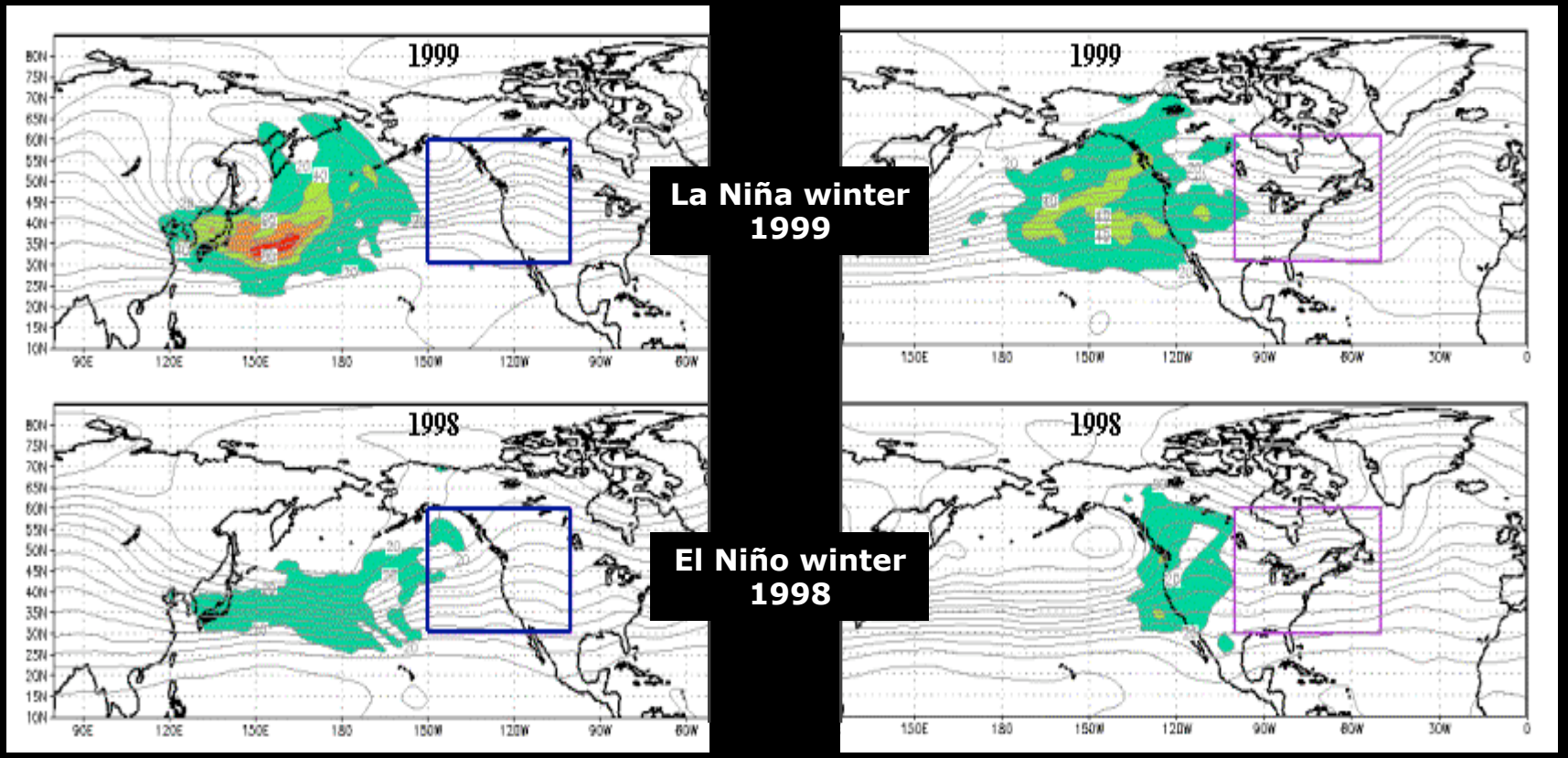
The influence of planetary time-mean flows on Rossby wave breaking

Idealized and Observed Potential Vorticity (PV)

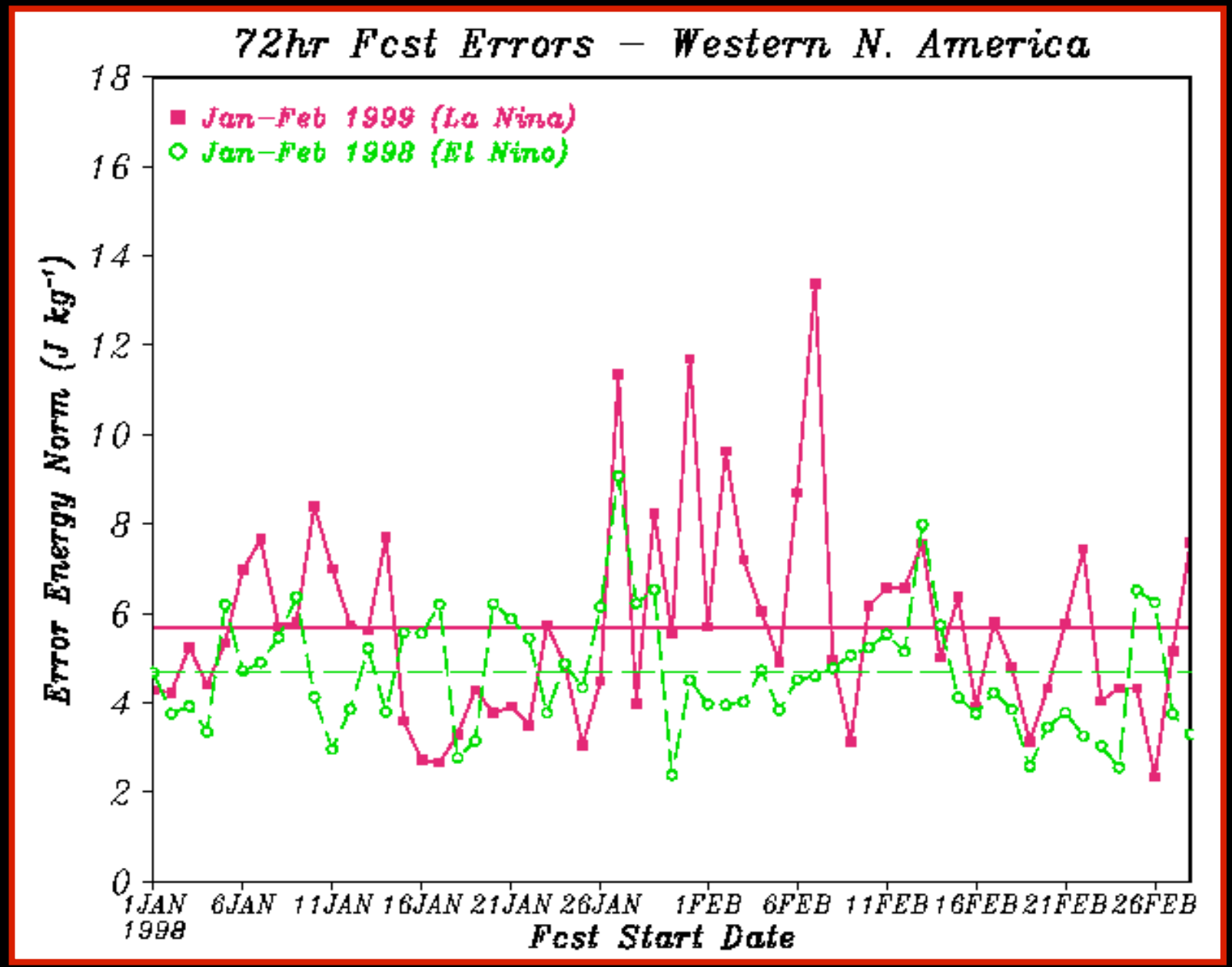


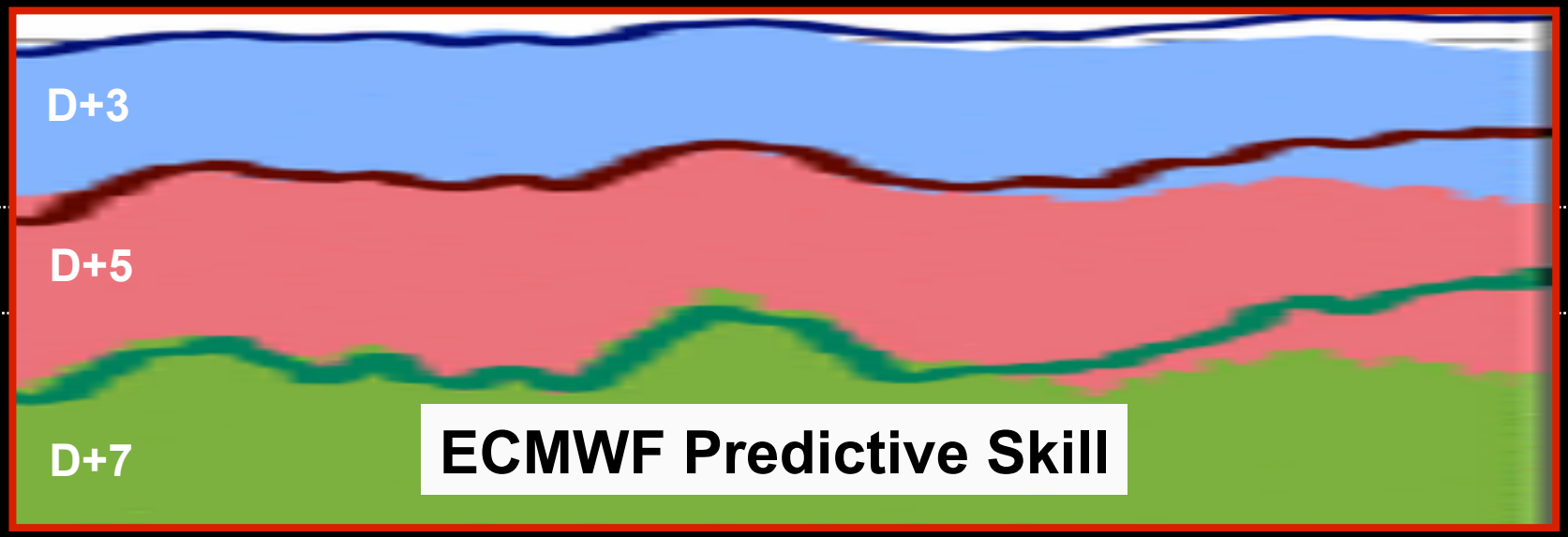
Upper panels: idealised simulations under the influence of anticyclonic (*left,* LC3) and cyclonic (*right,* LC2) time-mean meridional barotropic shear (from Davies *et al* 1991). *Lower panels*: ECMWF observed PV at three isentropic levels for the cold and warm phases of ENSO, respectively; Shapiro *et al.* 2001 *QJRMS*.

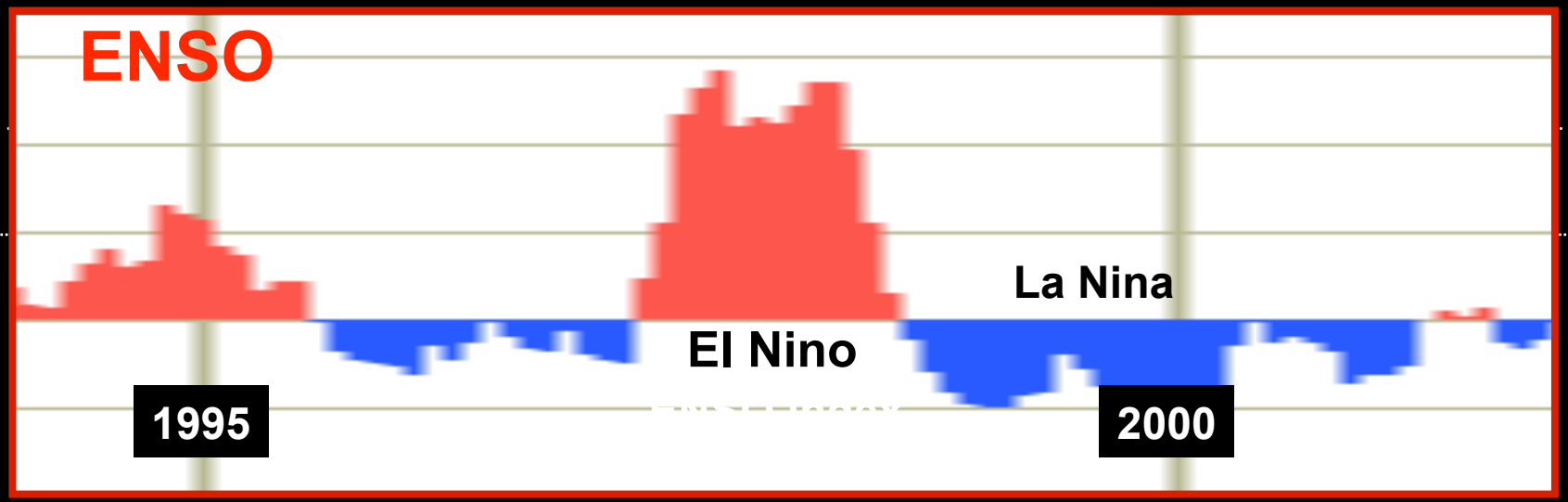
Sensitivity to initial conditions



Shading is the sensitivity calculated using the NOGAPS forecast and adjoint models. Contours are mean 500-mb ht. for January & February (courtesy Rolf Langland (NRL/Monterey).


72hr Fcst Errors — Western N. America
Jan–Feb 1999 (La Nina)
Jan–Feb 1998 (El Nino)
Error Energy Norm (J kg⁻¹)
0
2
4
6
8
10
12
14
16
18
1JAN 1998
6JAN
11JAN
16JAN
21JAN
26JAN
1FEB
6FEB
11FEB
16FEB
21FEB
26FEB
Fcst Start Date

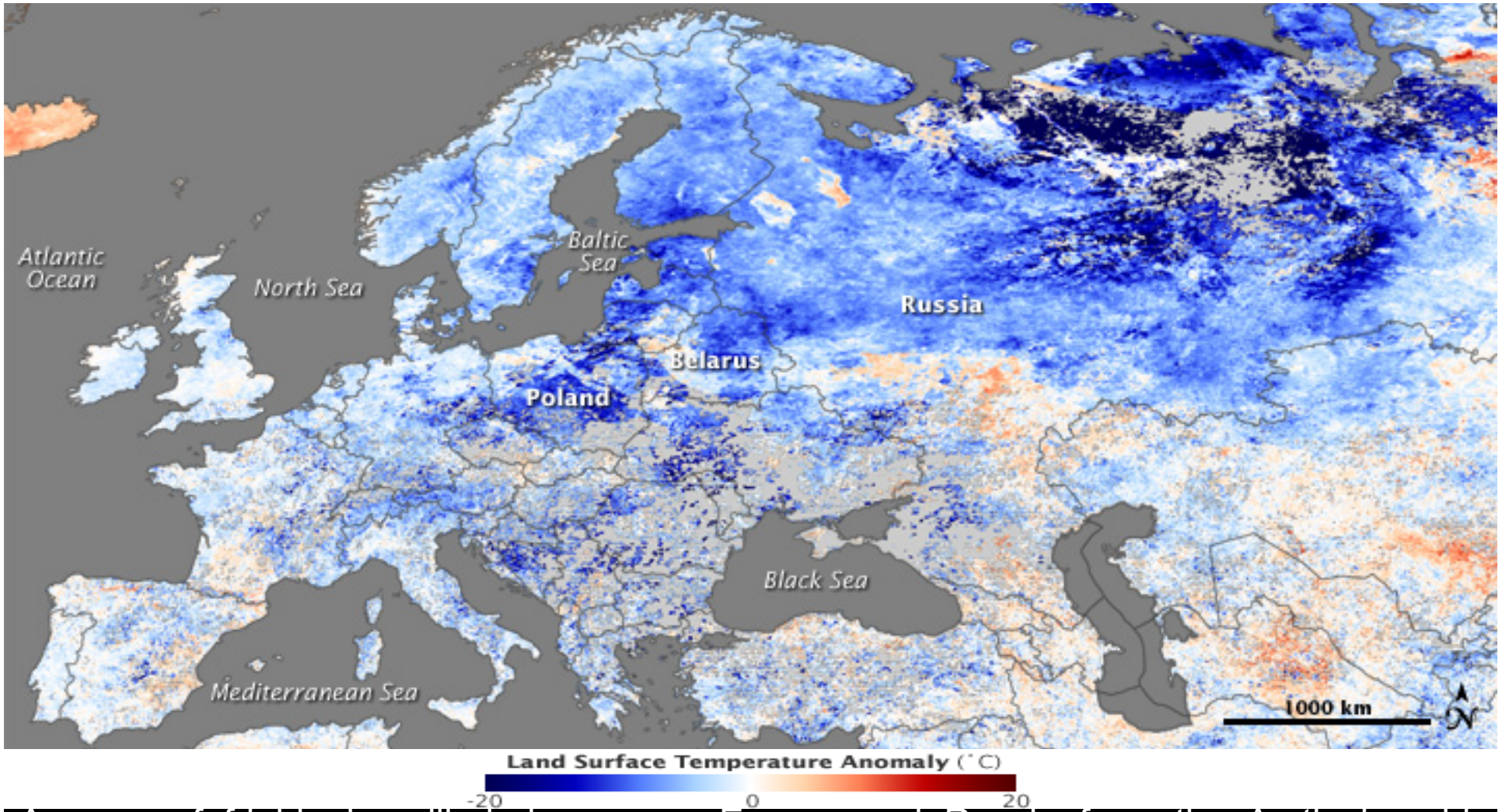

D+3
D+5
D+7
ECMWF Predictive Skill


ENSO
La Nina
El Nino
1995
2000

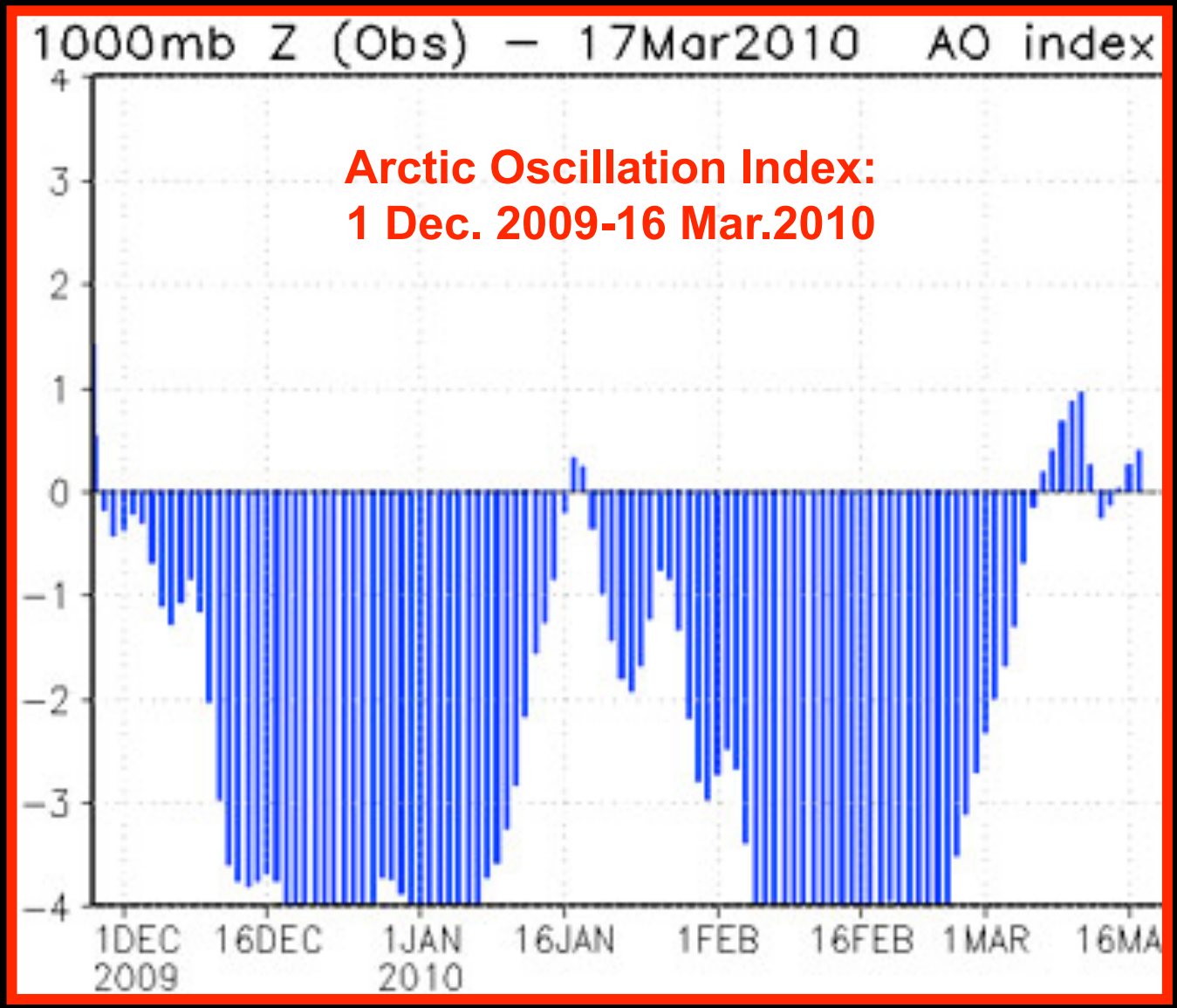

.ב

Preliminary indications continue to suggest that winter temperatures are likely to be near or above average over much of Europe including the UK Winter 2009/10 is likely to be milder than last year for the UK, but there is still a 1 in 7 chance of a cold winter

Britain facing one of the coldest winters in 100 years, experts predict Britain is bracing itself for temperatures hitting minus 16 degrees Celsius, forecasters have warned.

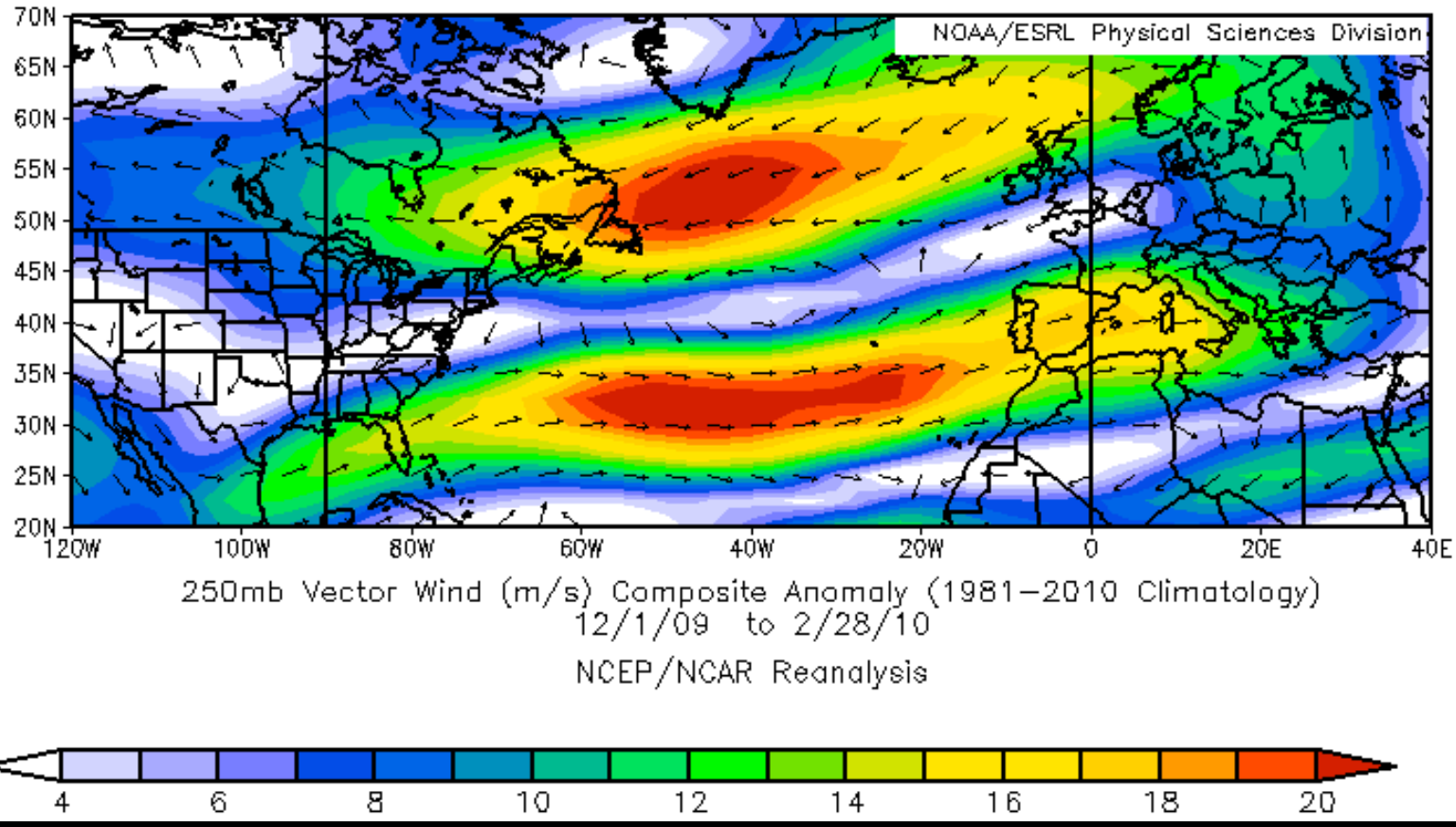


A wave of frigid air spilled down over Europe and Russia from the Arctic in mid-December, creating a deadly cold snap. According to BBC.com, at least 90 people had died in Europe, including 79 people, mostly homeless, in Poland. In places, the bitter cold was accompanied by heavy snow, which halted rail and air traffic. This image shows the impact of the cold snap on land surface temperatures across the region from December 11–18, 2009, compared to the 2000–2008 average.


1000mb Z (Obs) – 17Mar2010 AO index
Arctic Oscillation Index:
1 Dec. 2009-16 Mar.2010
4
3
2
1
0
−1
−2
−3
−4
1DEC 2009
16DEC
1JAN 2010
16JAN
1FEB
16FEB
1MAR
16MA

250 mb Vector Wind Anomaly

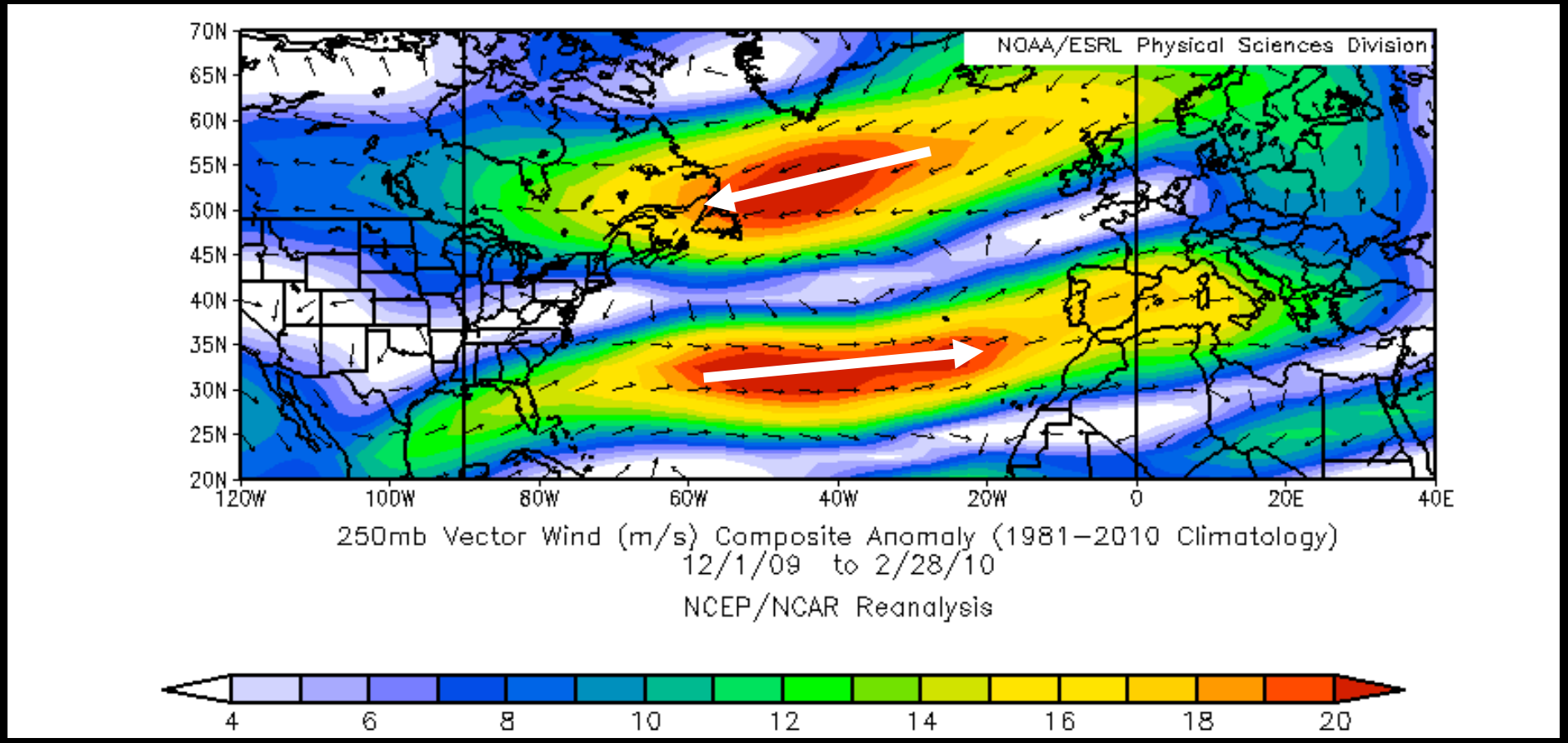
1 Dec 2009–28 Feb 2010



Negative AO regime

250 mb Vector Wind Anomaly

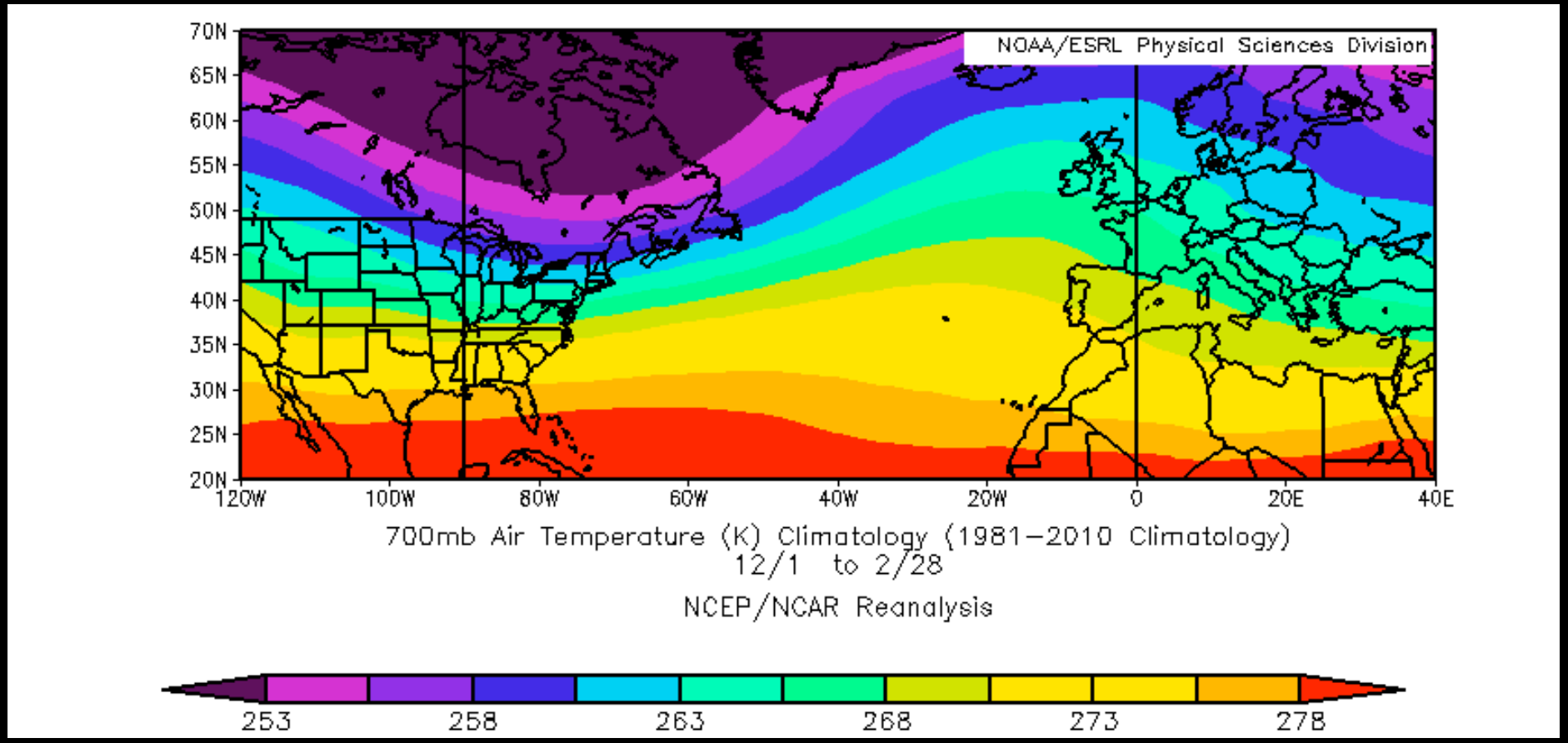
1 Dec 2009–28 Feb 2010



Negative AO regime

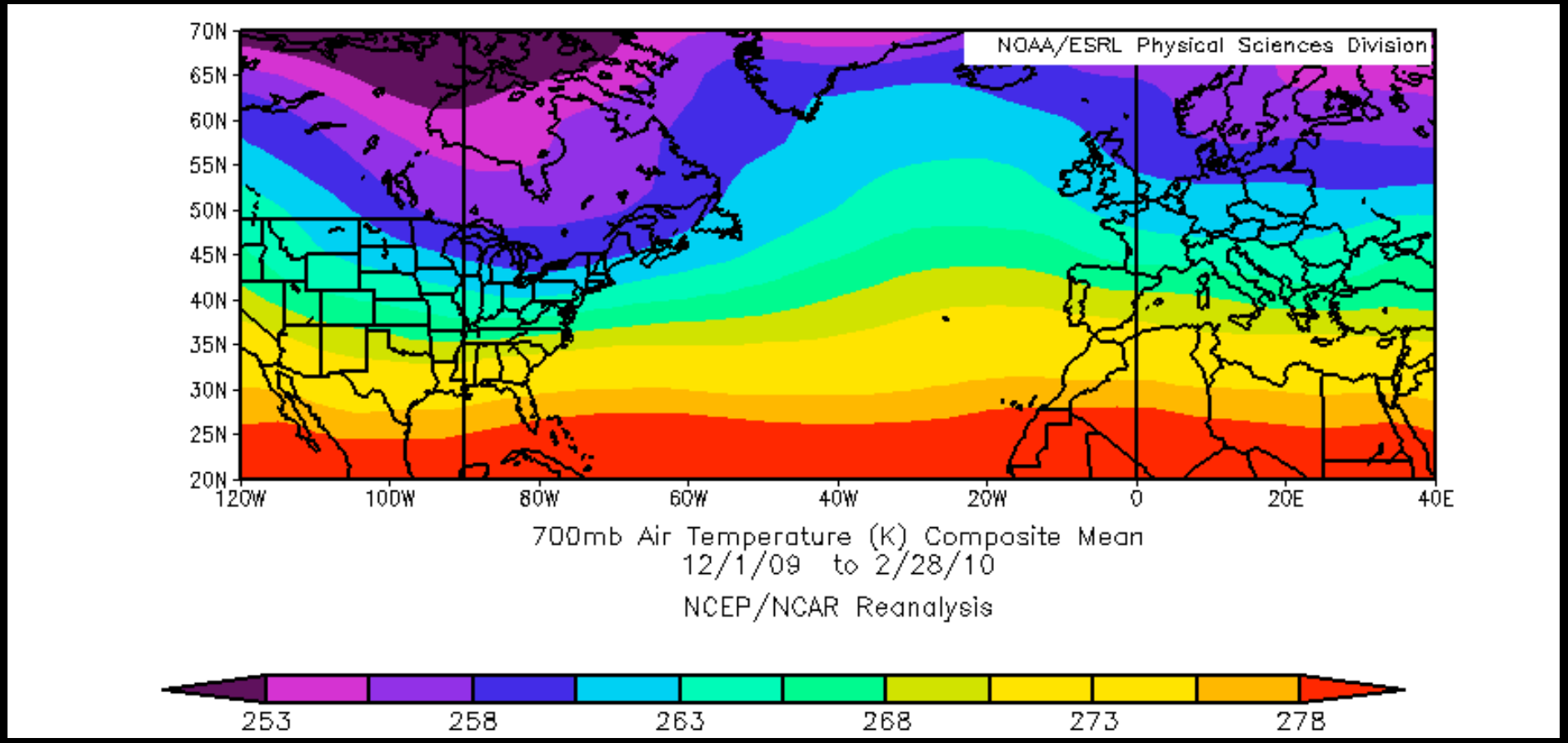
700-mb Temperature Long-Term Climatology

1 Dec–28 Feb



700 mb Temperature Mean

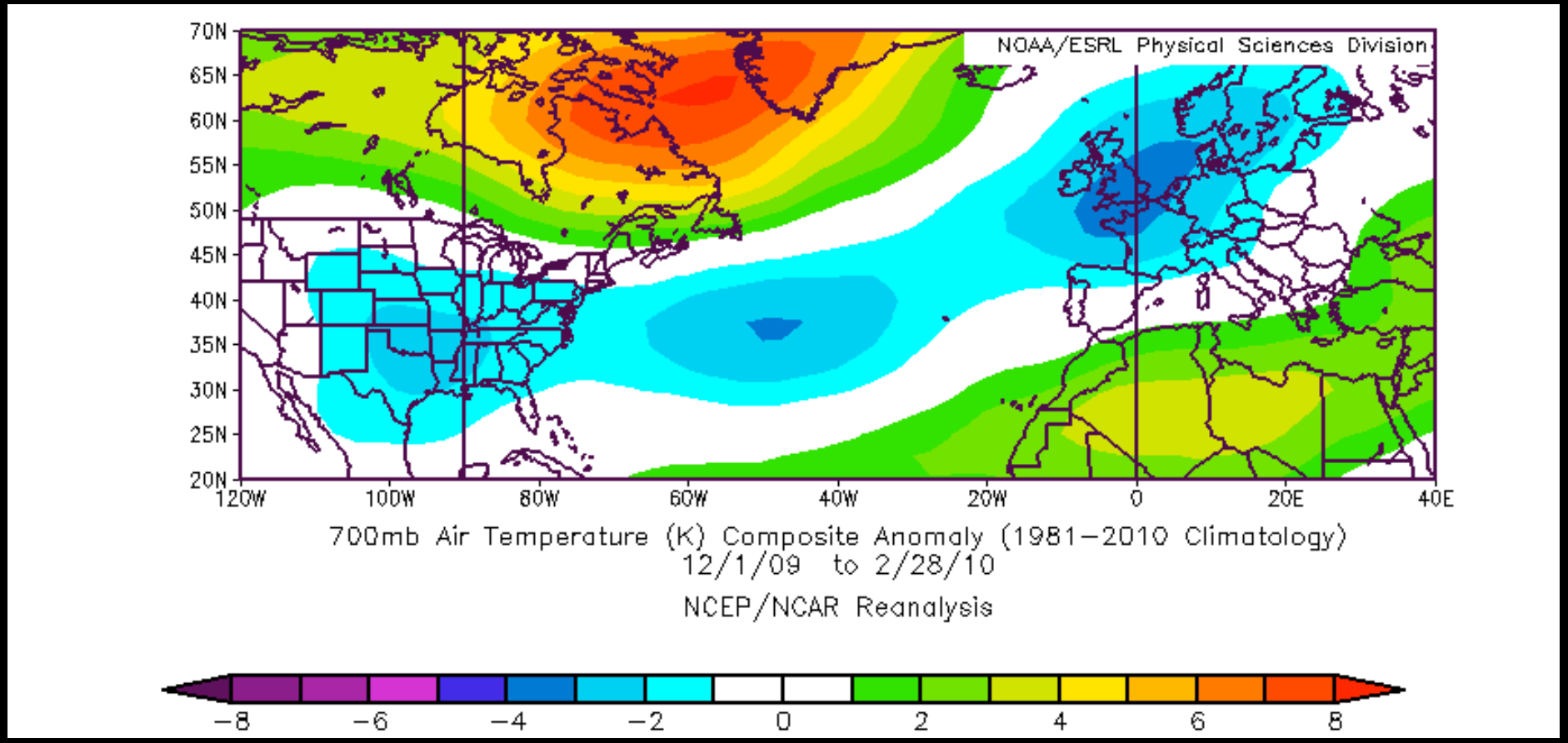
1 Dec 2009–28 Feb 2010



Negative AO regime

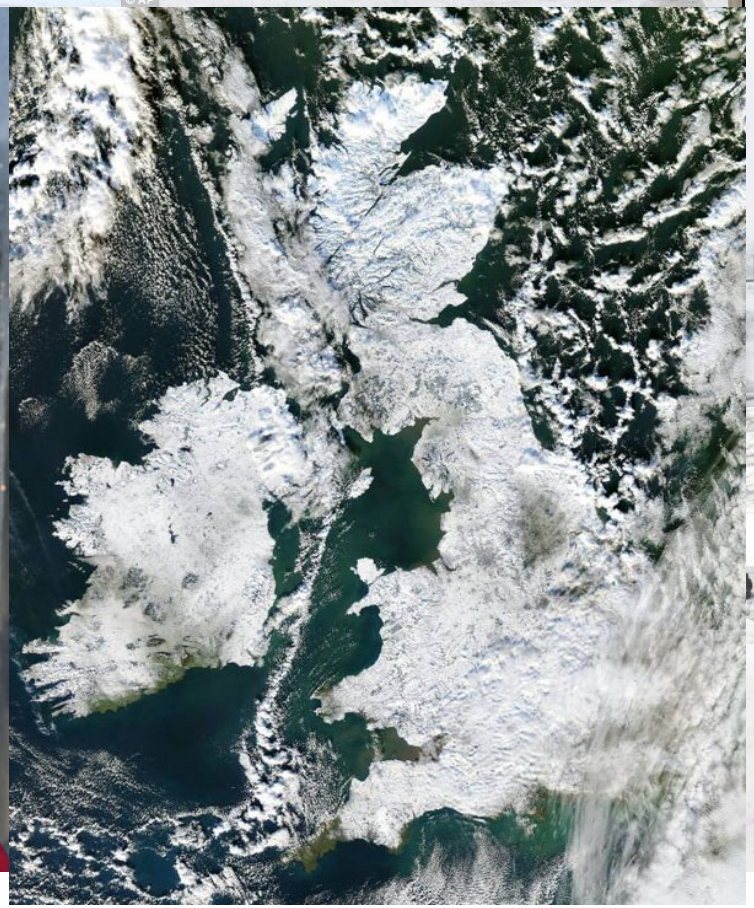
700 mb Temperature Anomaly

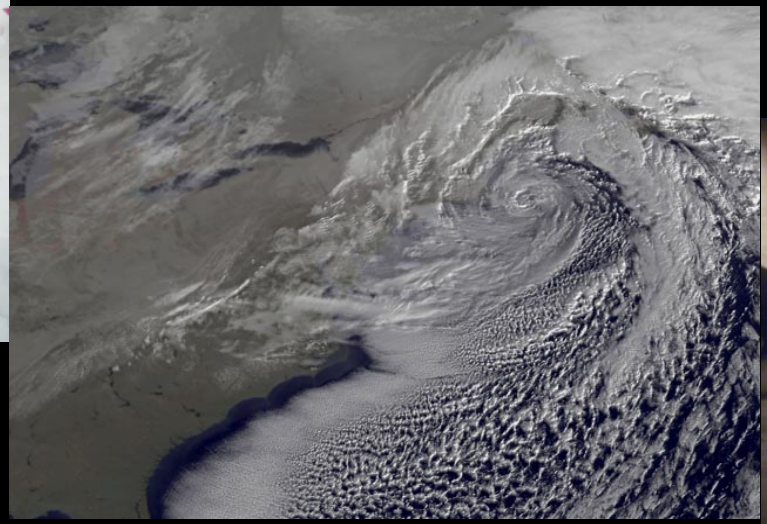
1 Dec 2009–28 Feb 2010



Negative AO regime

“Snow causes travel chaos in the UK, as the cold snap continues”
December 2010



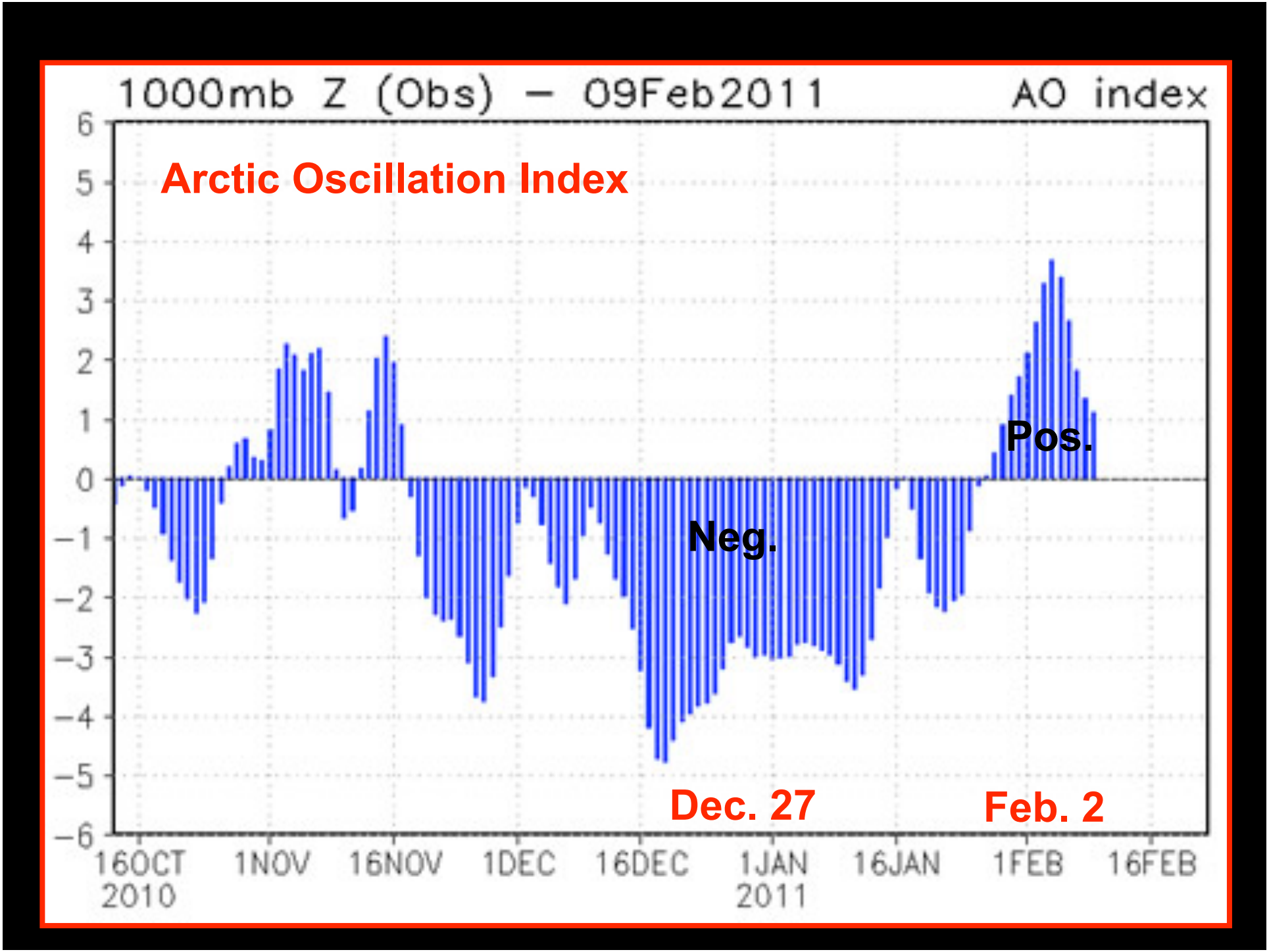


26-27 December 2010

Northeastern US

Snow storm

2-3 February 2011
New England Snow Storm


1000mb Z (Obs) – 09Feb2011
AO index
Arctic Oscillation Index
6
5
4
3
2
1
0
−1
−2
−3
−4
−5
−6
Pos.
Neg.
Dec. 27
Feb. 2
16OCT
2010
1NOV
16NOV
1DEC
16DEC
1JAN
2011
16JAN
1FEB
16FEB

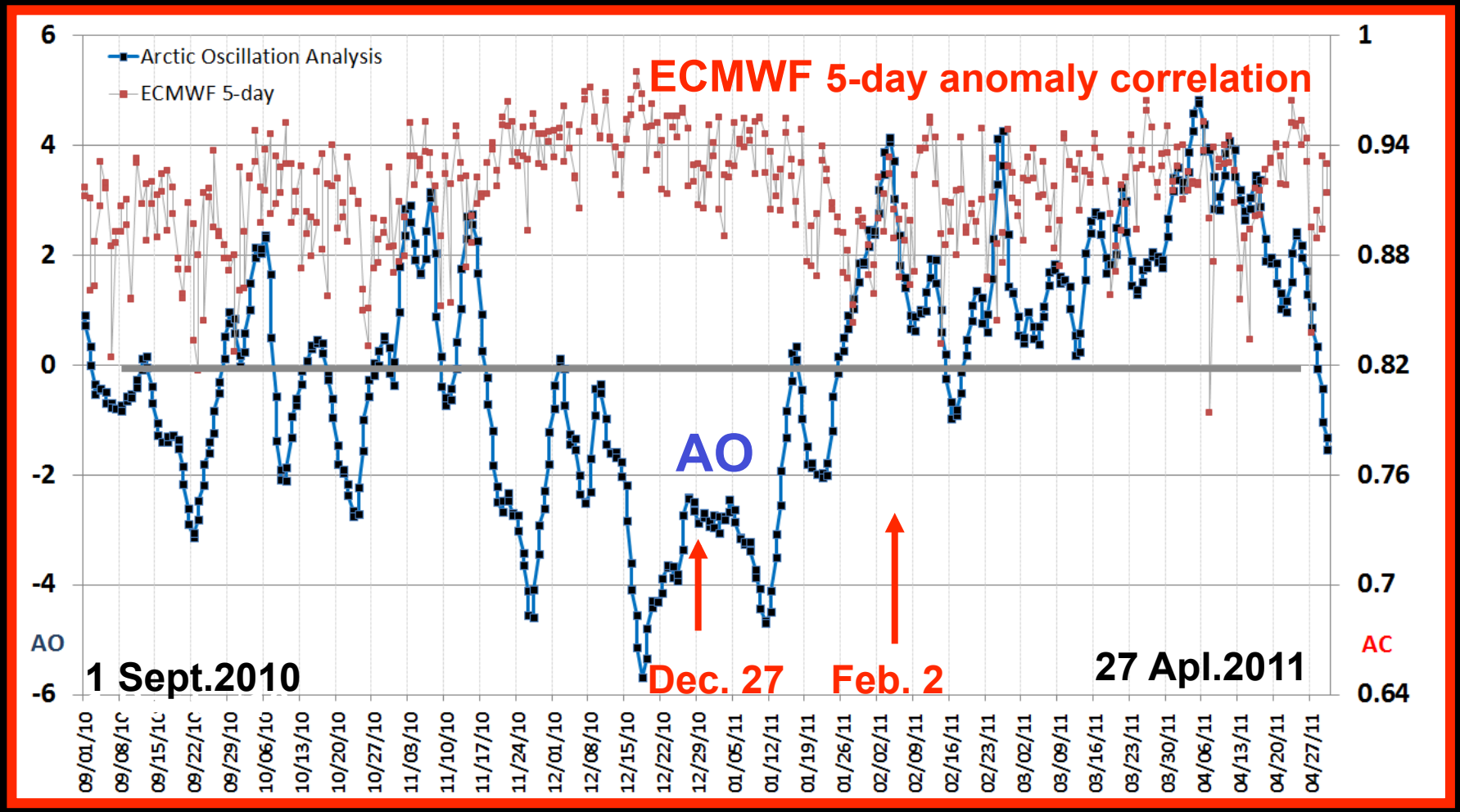
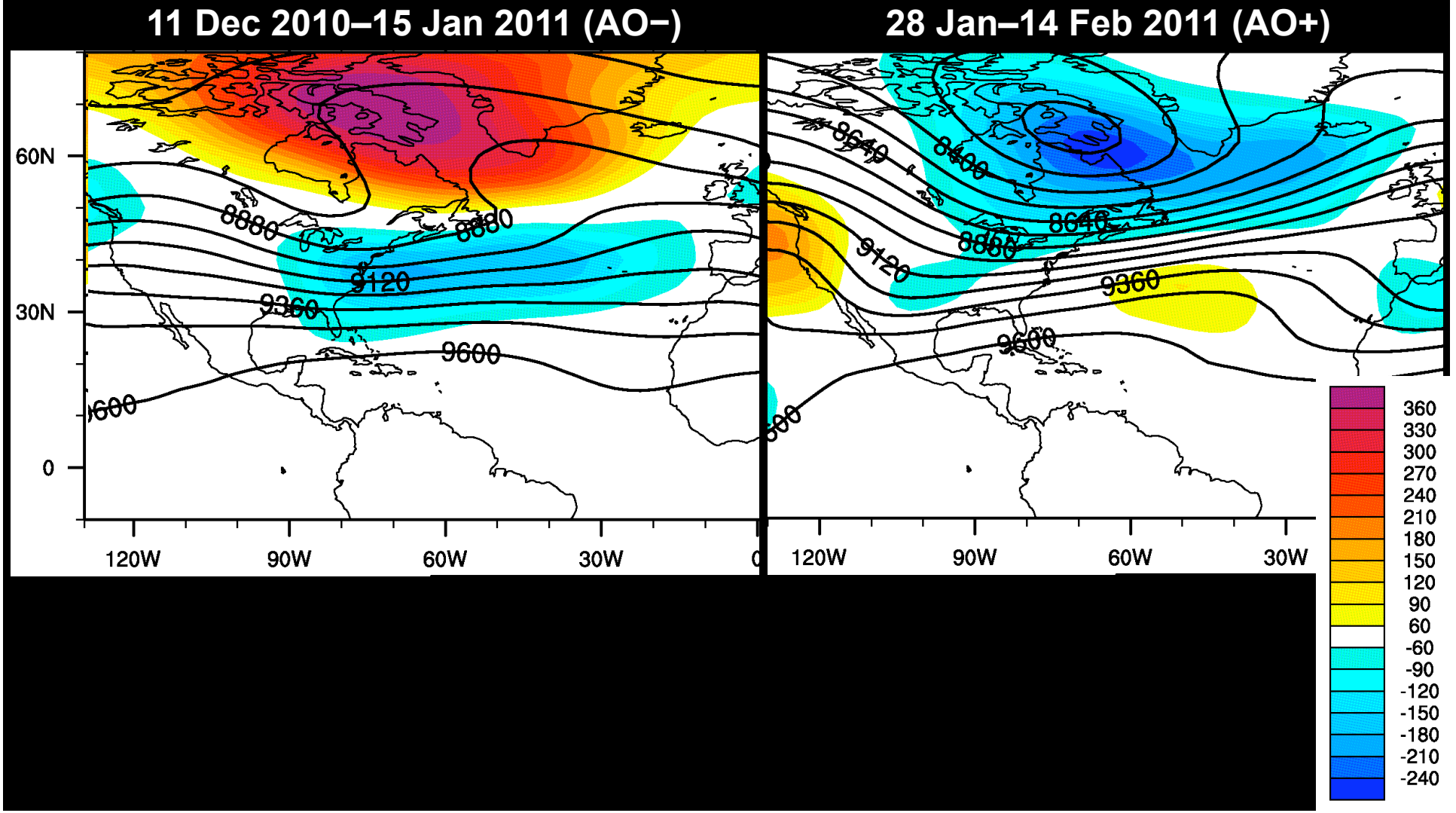
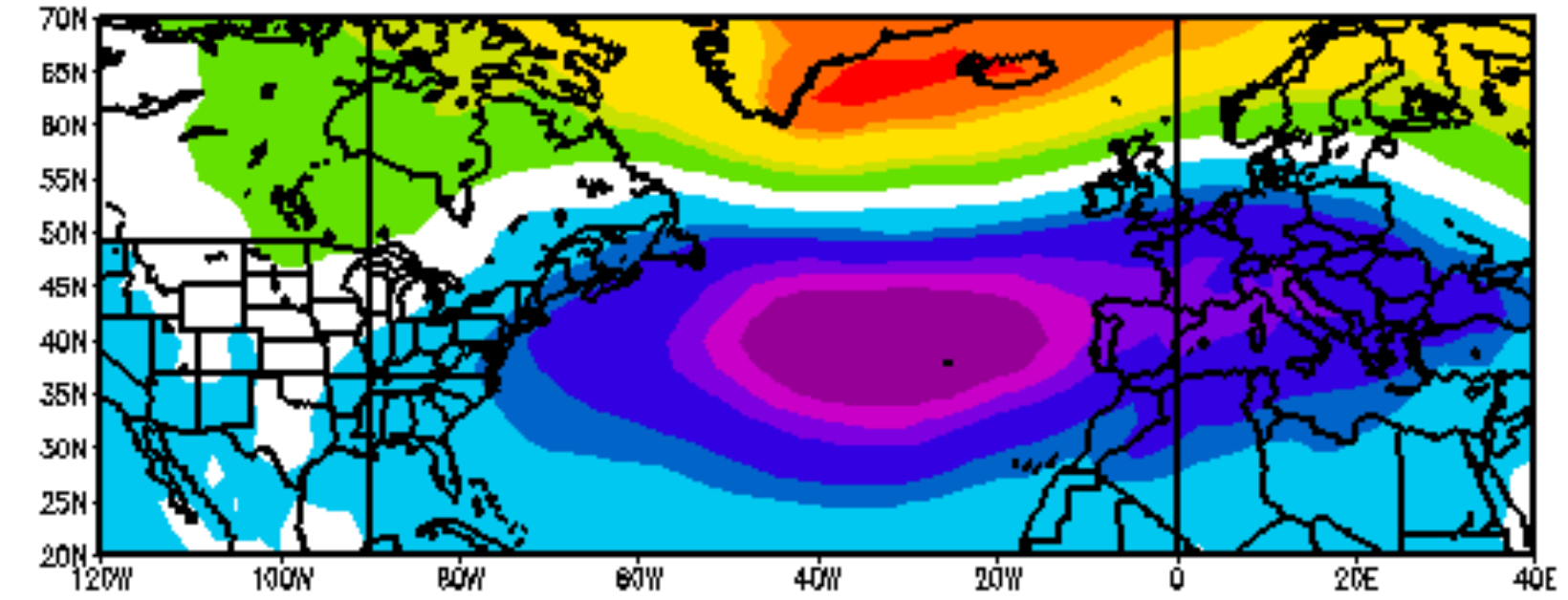


Figure 1: **Arctic Oscillation (AO)** and **ECMWF** **5-day anomaly correlation** of 500hPa height in the northern hemisphere (20°N-80°N), from 1 Sept 2010 to 27 Apr 2011. Note the period of high skill from mid-November to mid-January associated with negative AO phase. Forecast dropouts (low skill) occur during periods with positive AO phase and transitions between positive and negative AO phase; **Langland and Maue, NRLMRY**

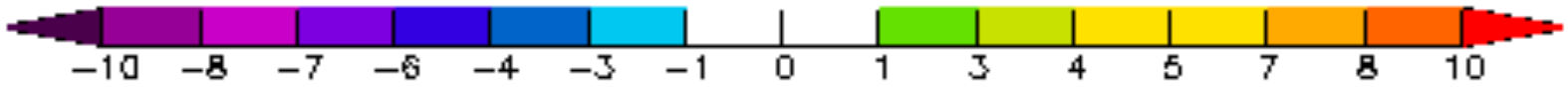
North Atlantic 300-mb Height Mean and Anomaly (m)

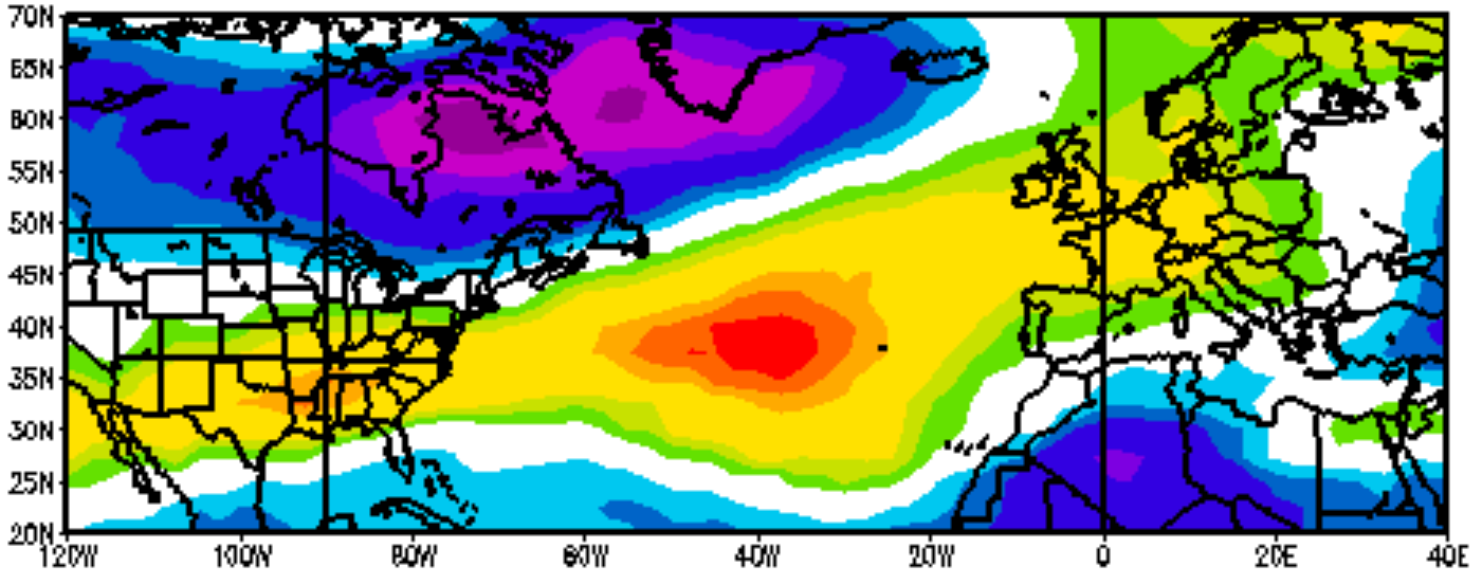




1000mb GEOPOTENTIAL HEIGHTS (dam) 121-DAY ANOMALY FOR:
Tue DEC 01 2009 - Wed MAR 31 2010

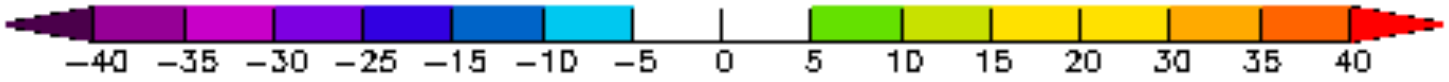
NCEP OPERATIONAL DATASET



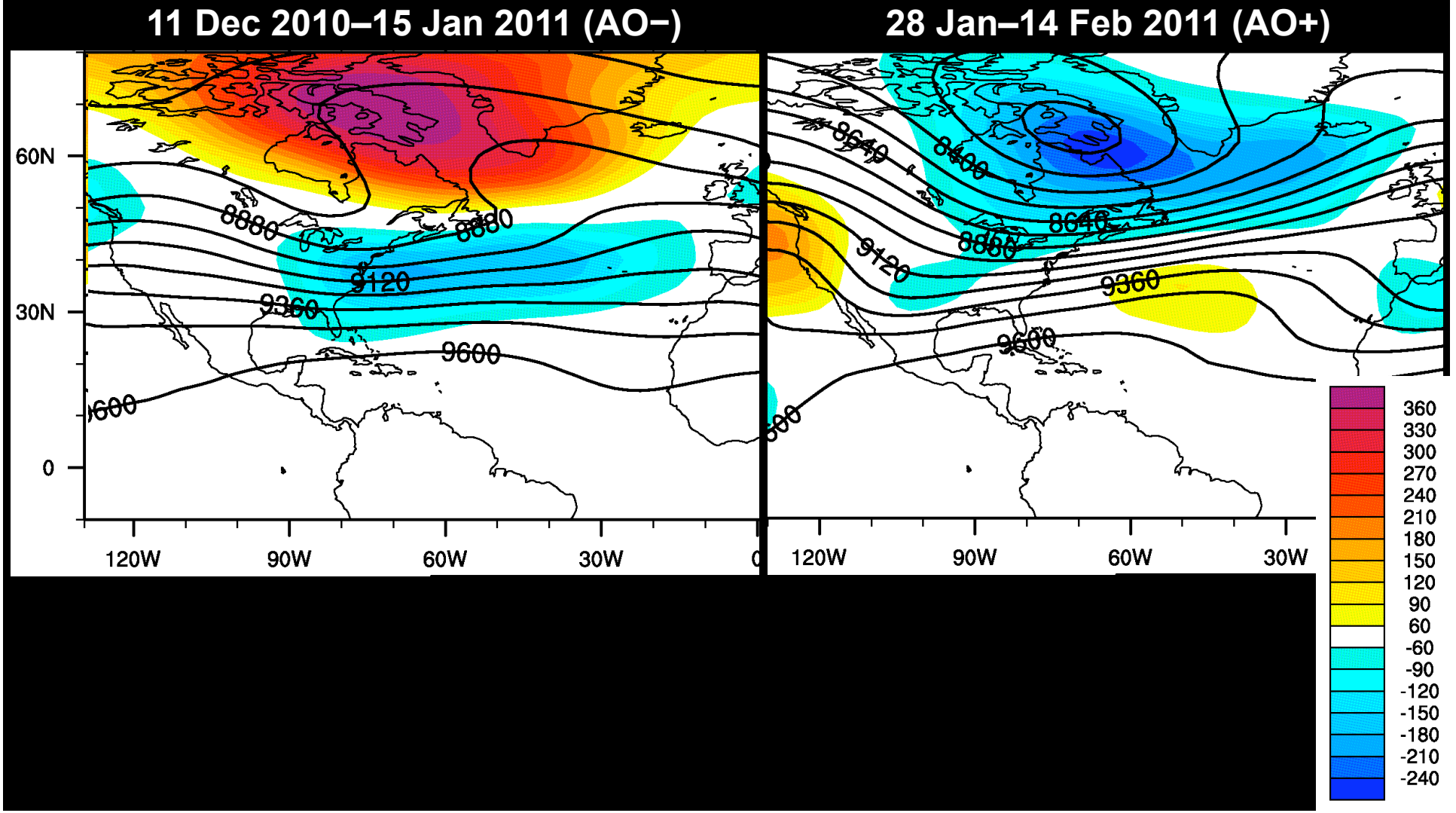


TROPOPAUSE PRESSURE (mb) 121-DAY ANOMALY FOR:
Tue DEC 01 2009 - Wed MAR 31 2010

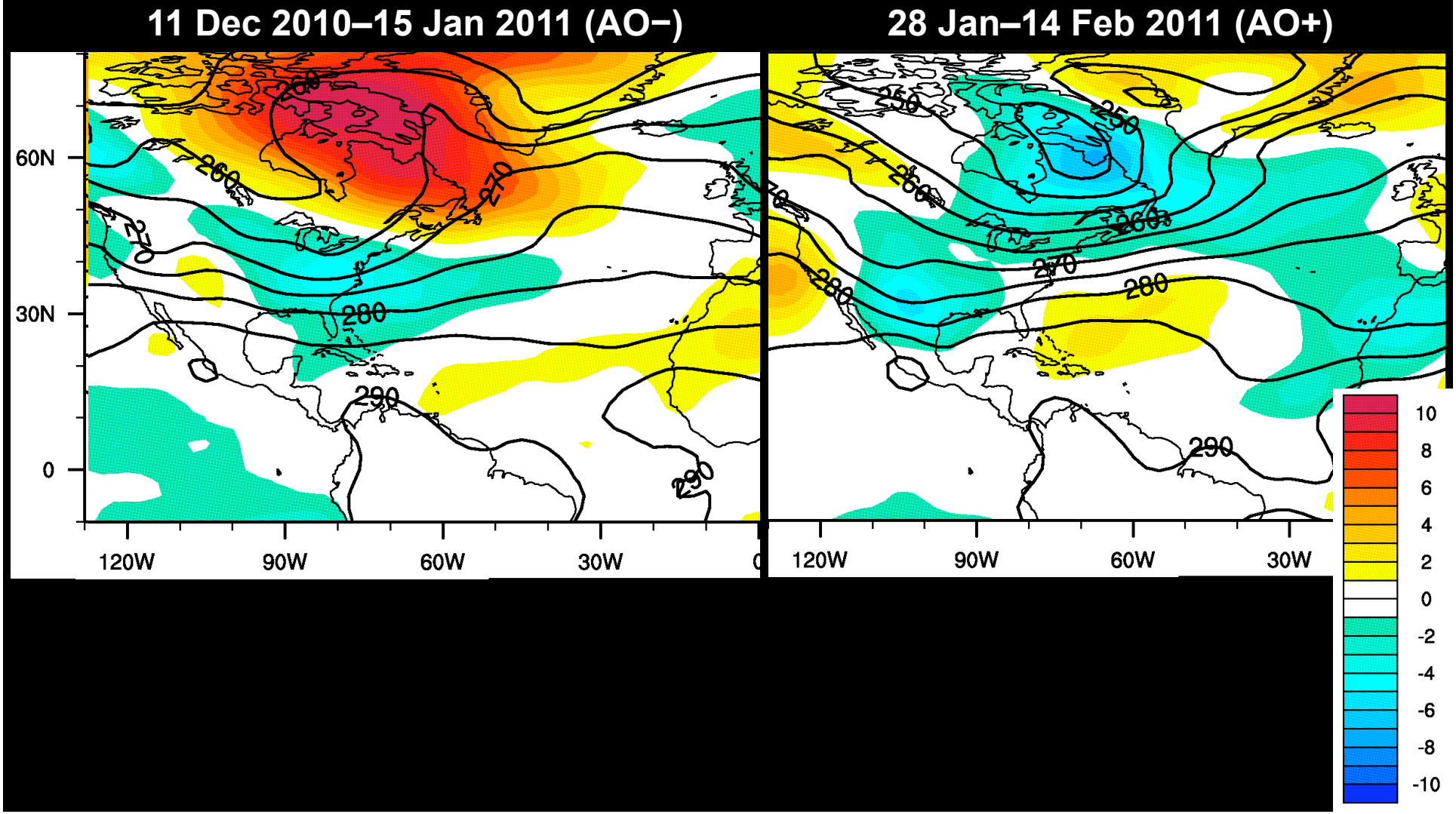
NCEP OPERATIONAL DATASET



North Atlantic 300-mb Height Mean and Anomaly (m)

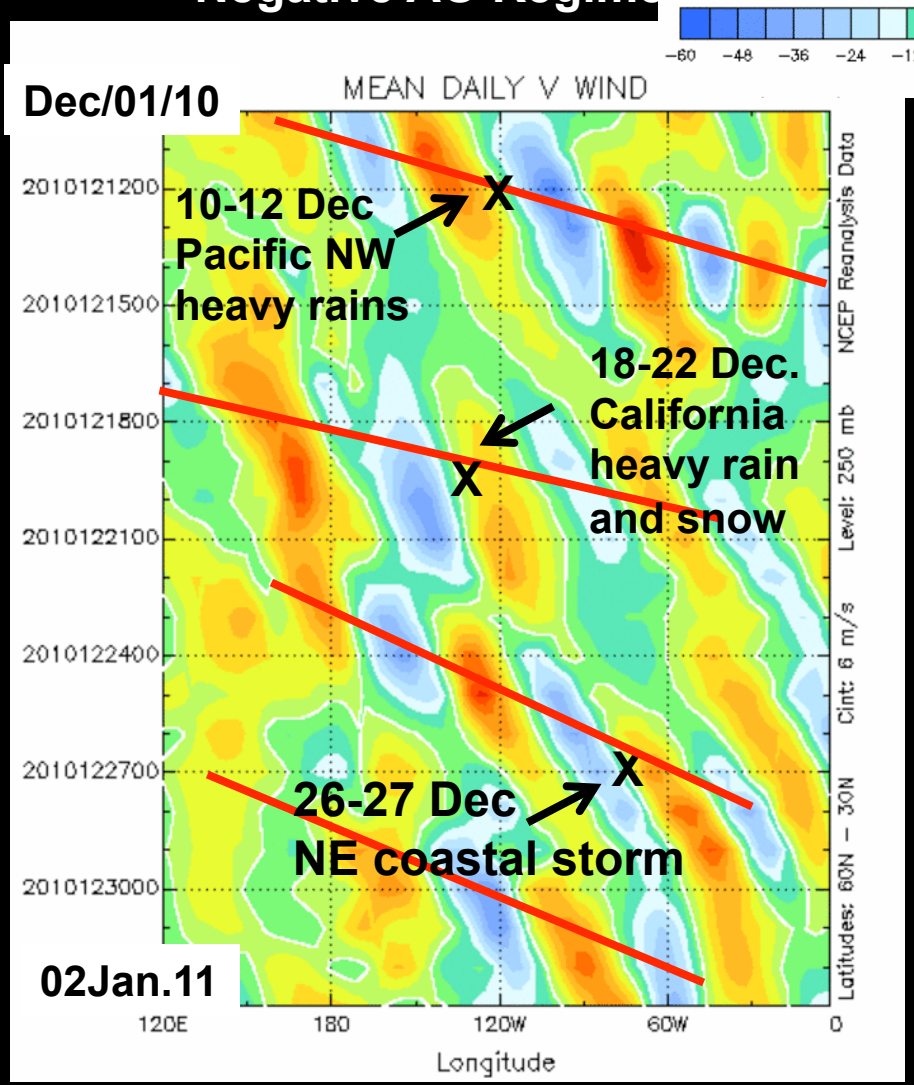


North Atlantic 850-mb Temperature Mean and Anomaly (K)



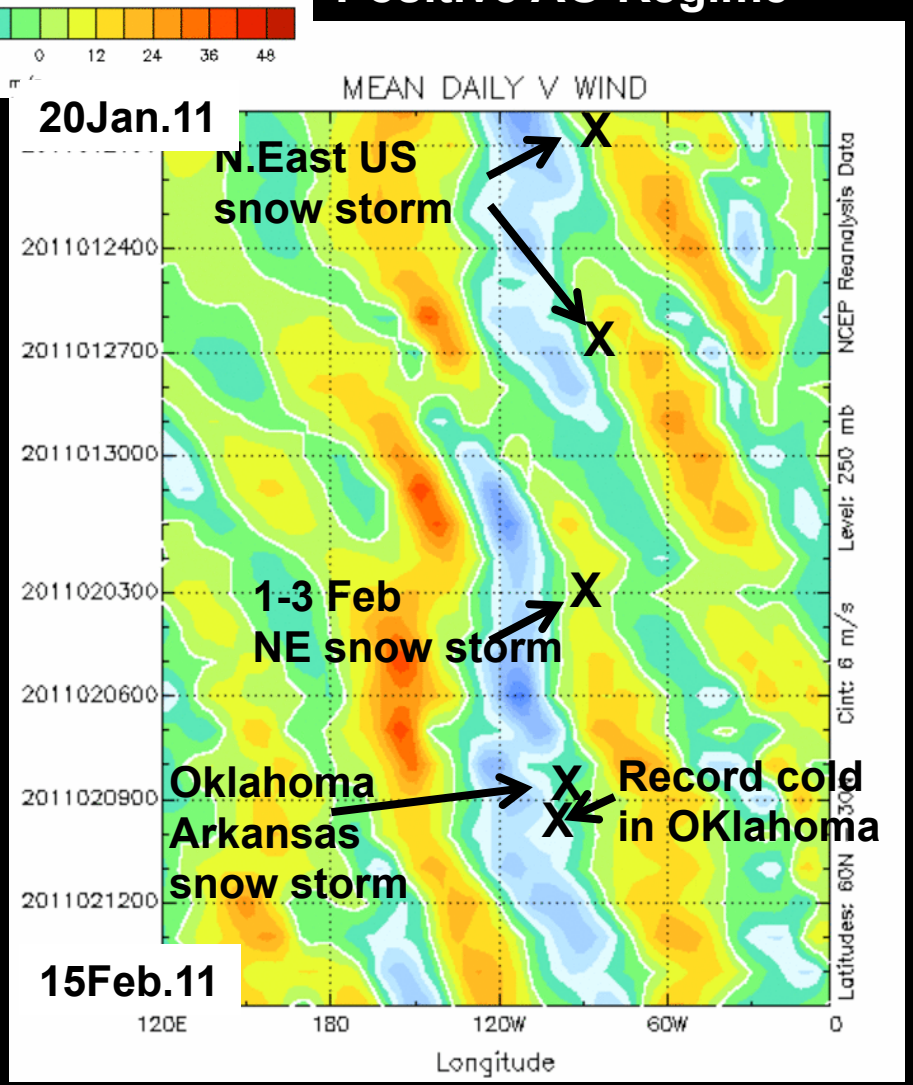
250-hPa Meridional Wind Component (lat avg 30–60°N.)

Negative AO Regime



Transient “wave packets”
associated with high-impact weather

Positive AO Regime

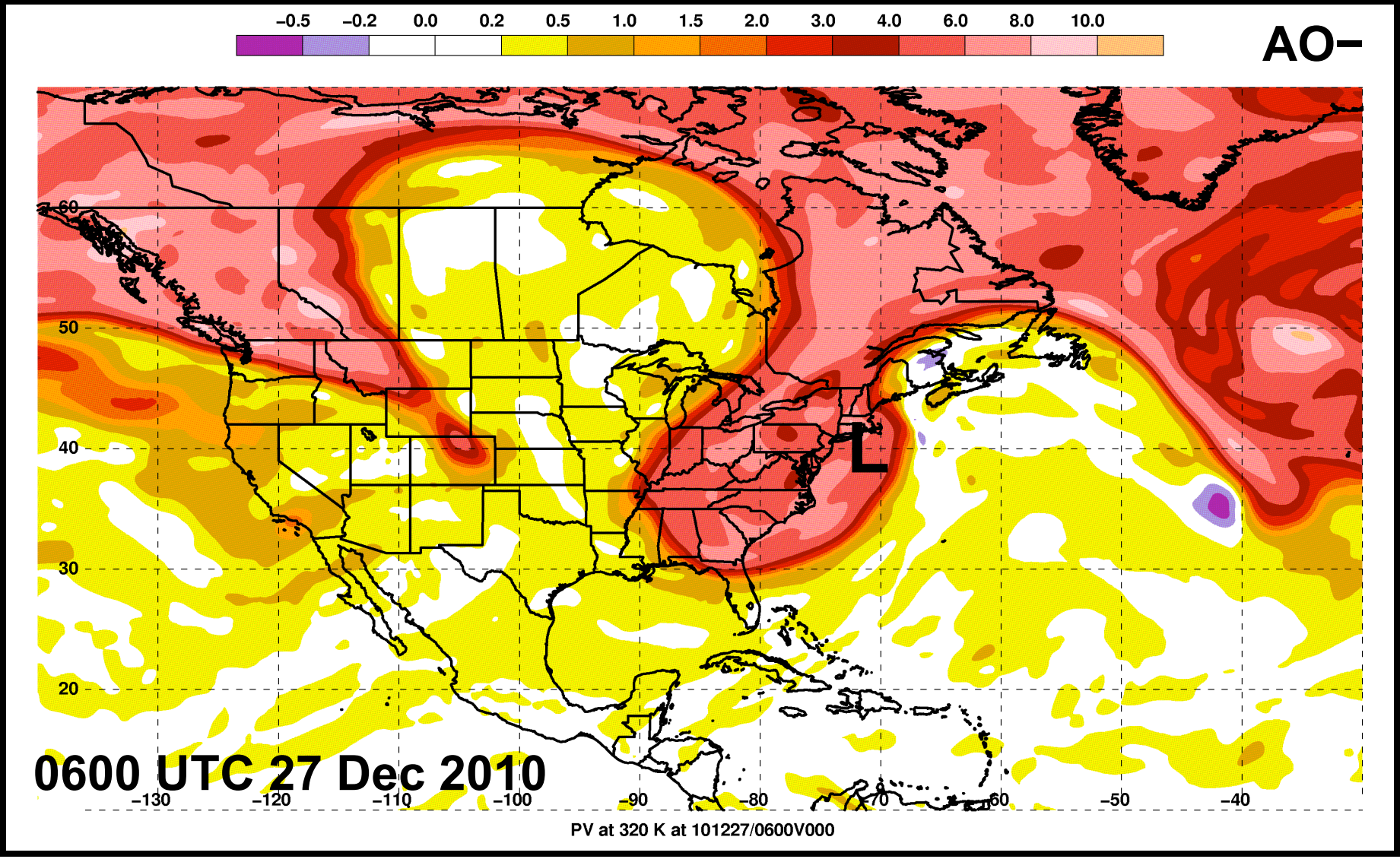


Persistent blocking pattern
associated with high-impact weather

Hovmoller diagrams were computed using the NOAA/ESRL Physical Sciences Division Interactive Plotting and Analysis website

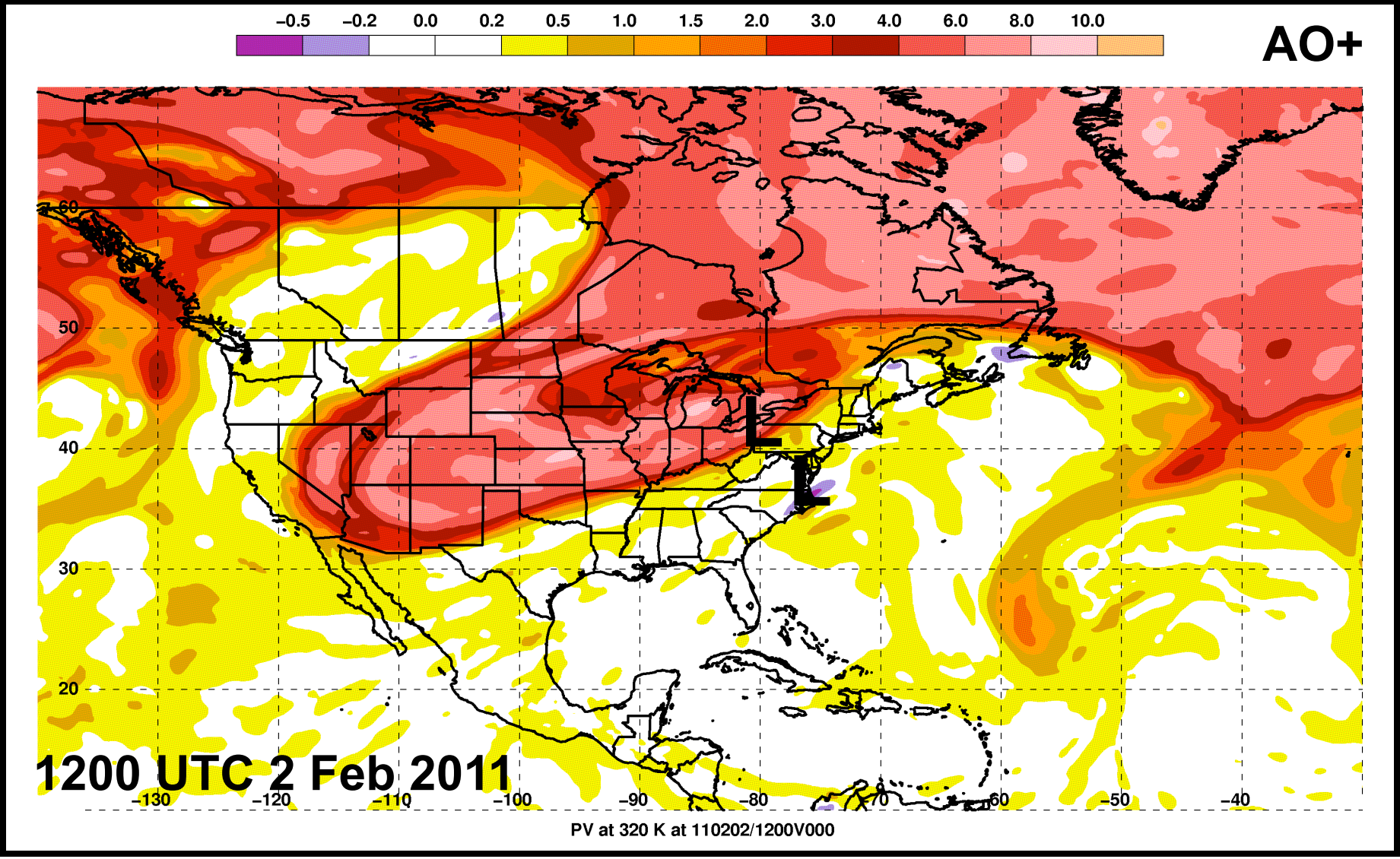
PV on 320 K Surface

Negative Phase AO



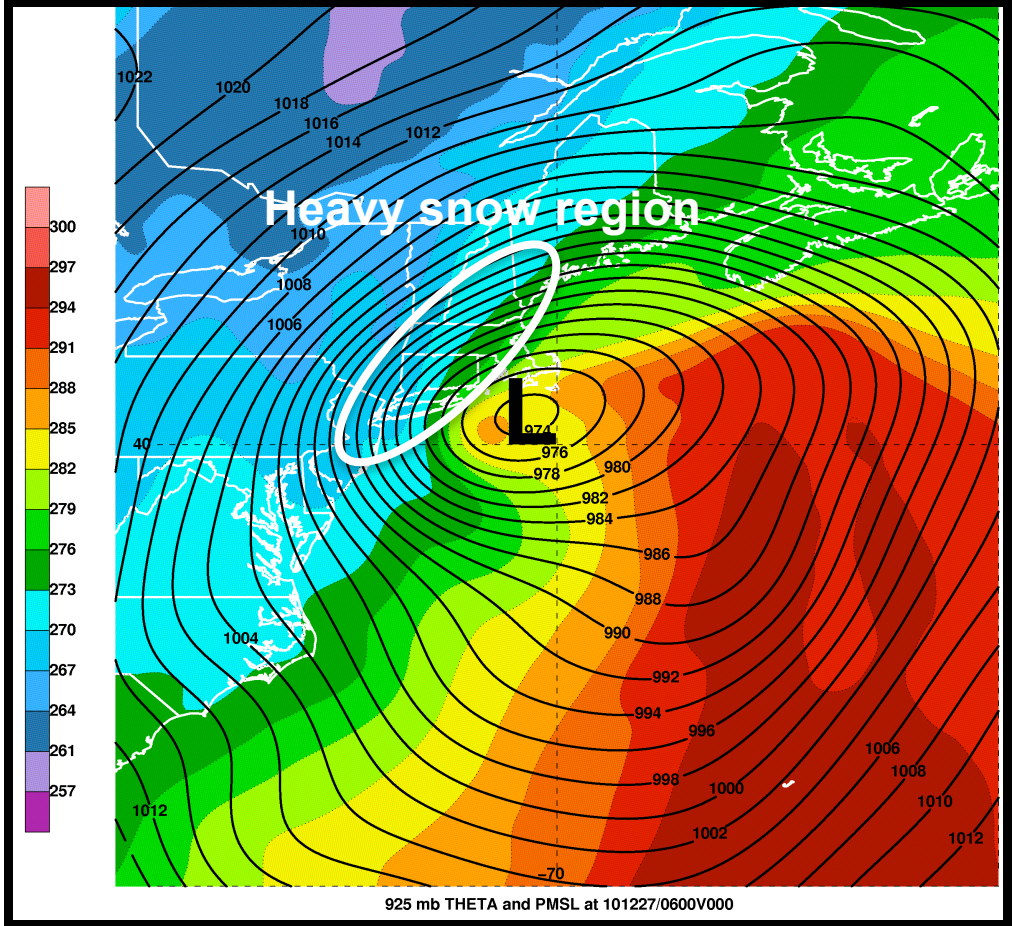
PV on 320 K Surface

Positive Phase AO



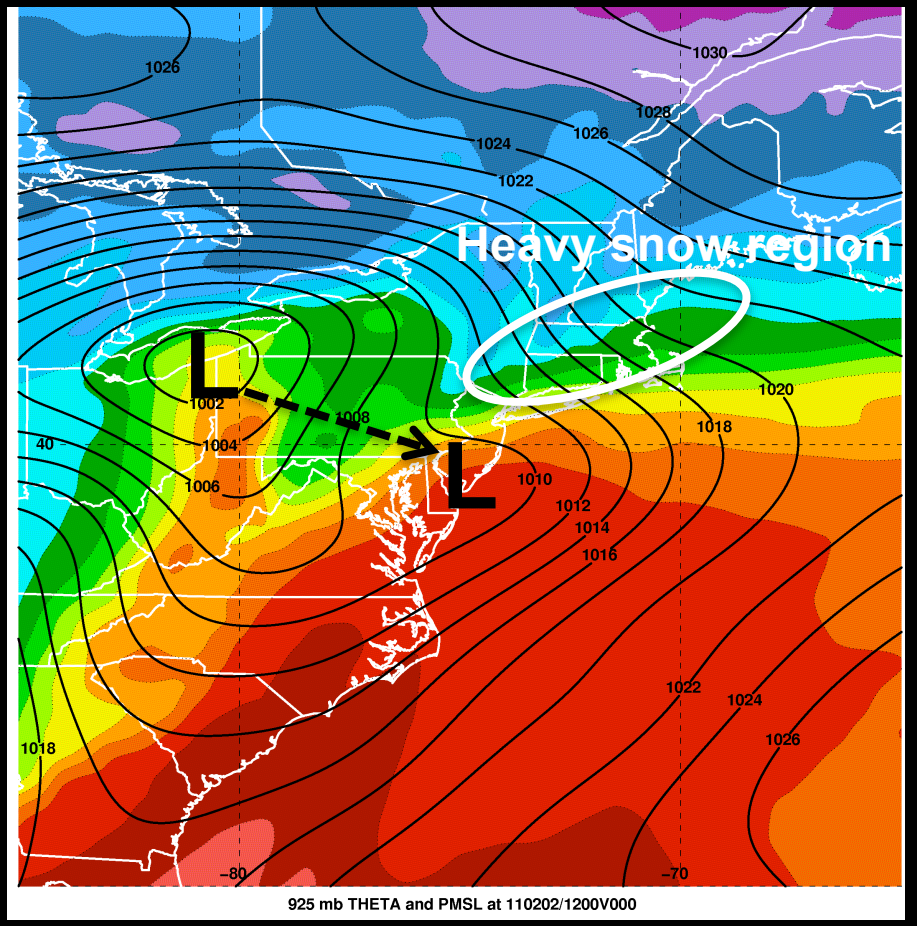
925-mb θ (K) and MSLP (mb)

0600 UTC 27 Dec 2010



Negative AO Phase

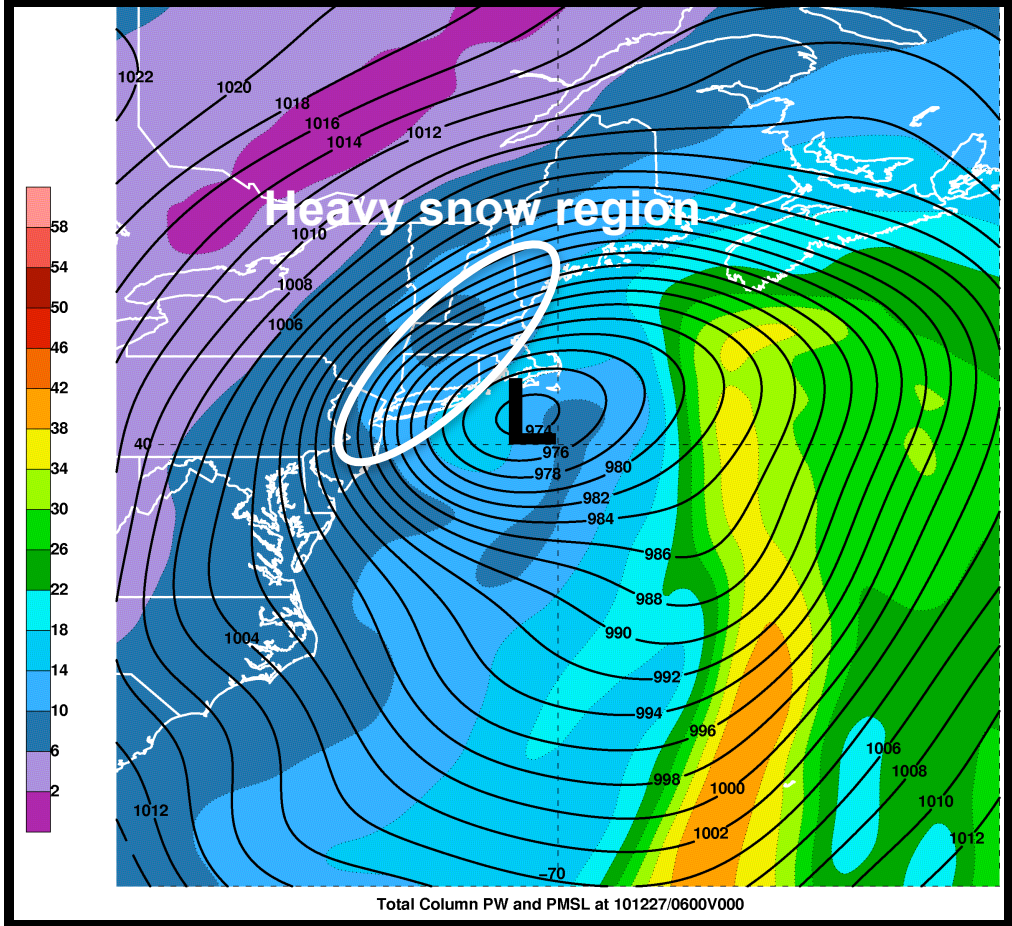
1200 UTC 2 Feb 2011



Positive AO Phase

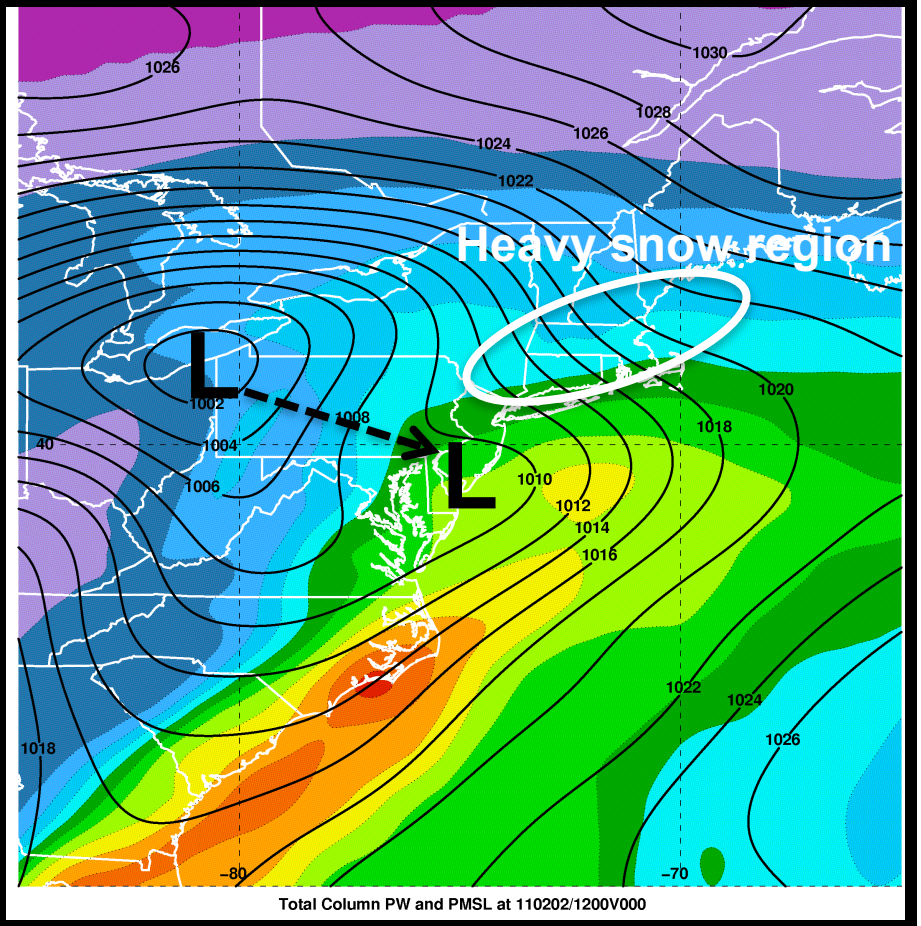
Precipitable Water (mm) and MSLP (mb)

0600 UTC 27 Dec 2010



Negative AO Phase

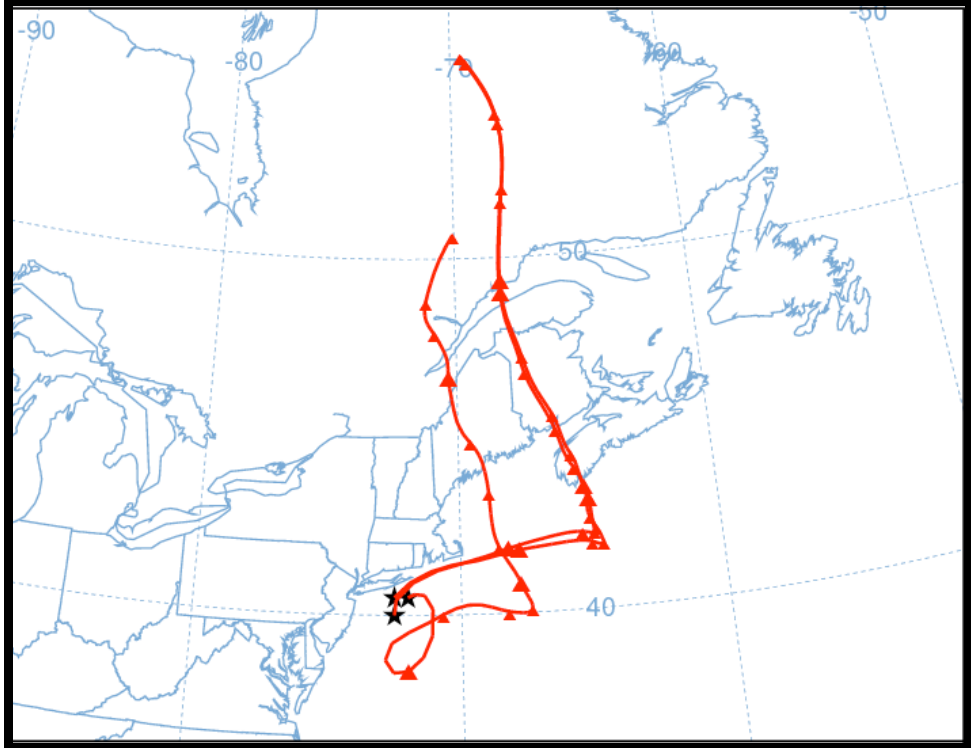
1200 UTC 2 Feb 2011



Positive AO Phase

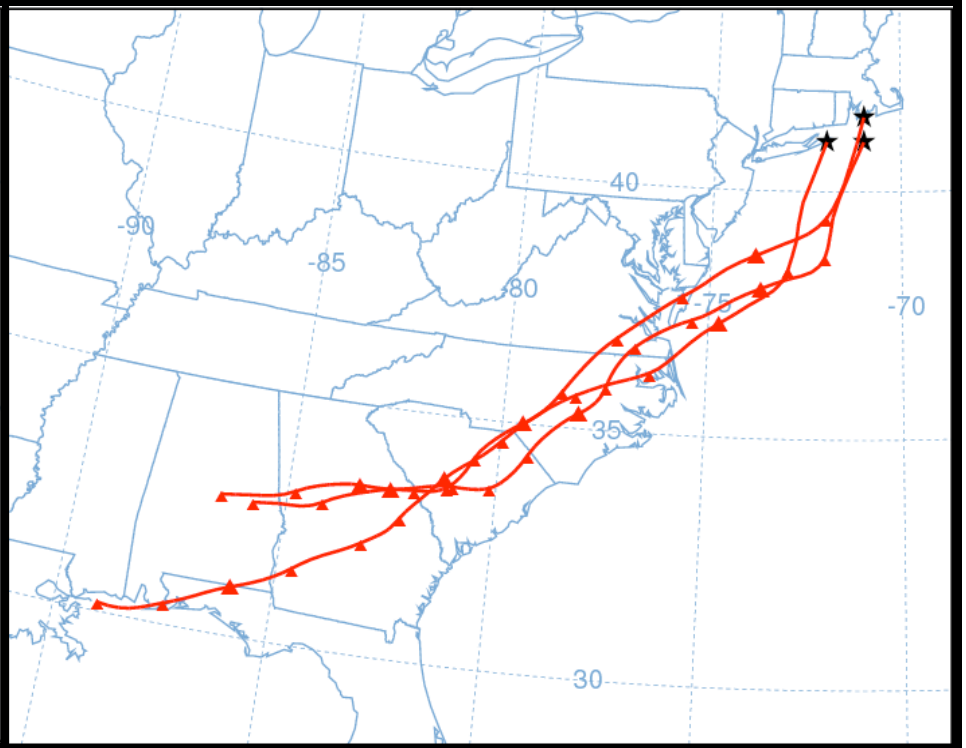
72-h Backward trajectories starting at 1500 m. MSL

Starting at 0600 UTC 27 Dec 2010



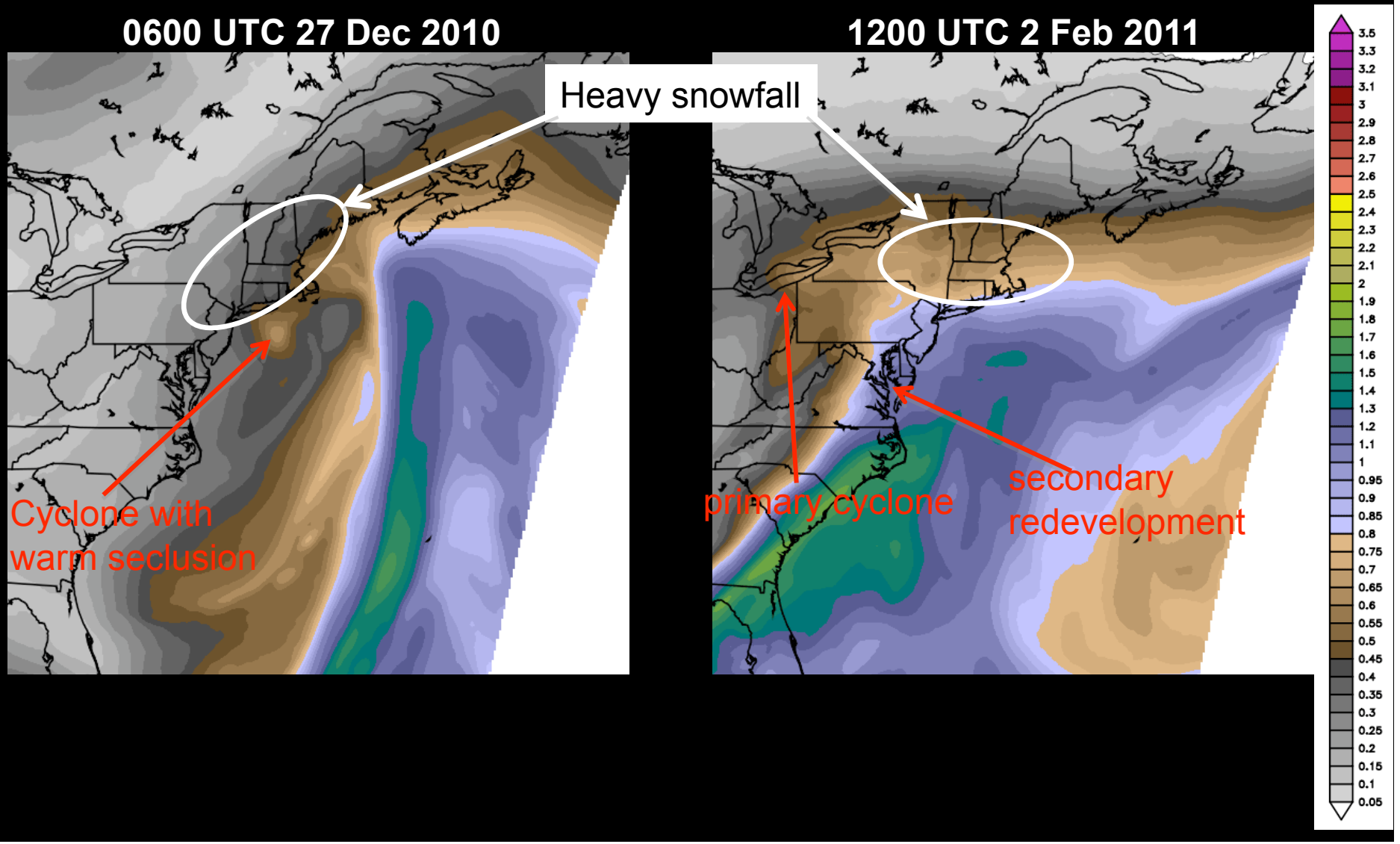
- LC2 during negative AO phase
- Air parcels near heavy snow region originate well north of warm front

Starting at 1200 UTC 2 Feb 2011

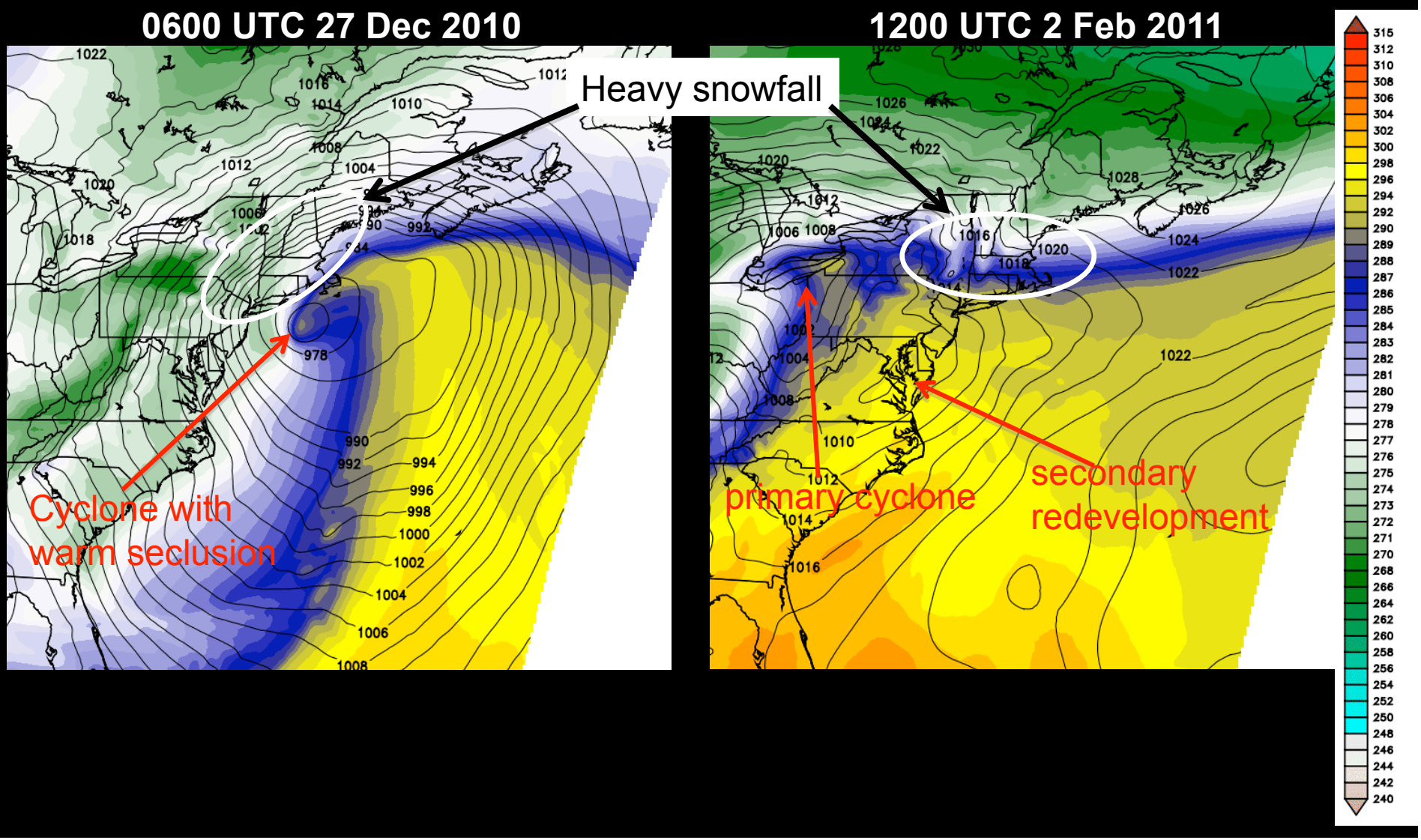


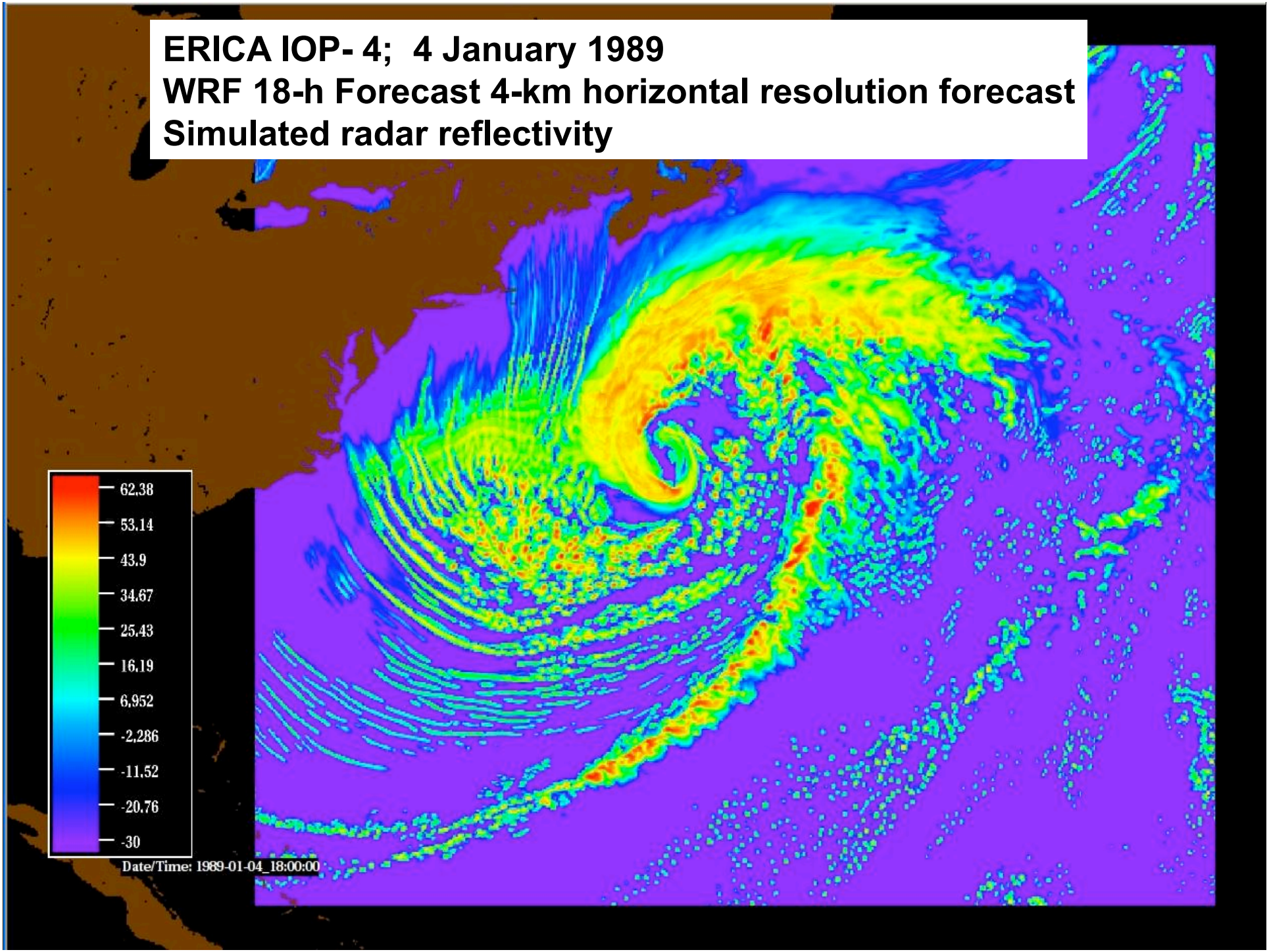
- LC1 during positive AO phase
- Air parcels near heavy snow region originate in cyclone warm sector
- Direct tropical moisture feed

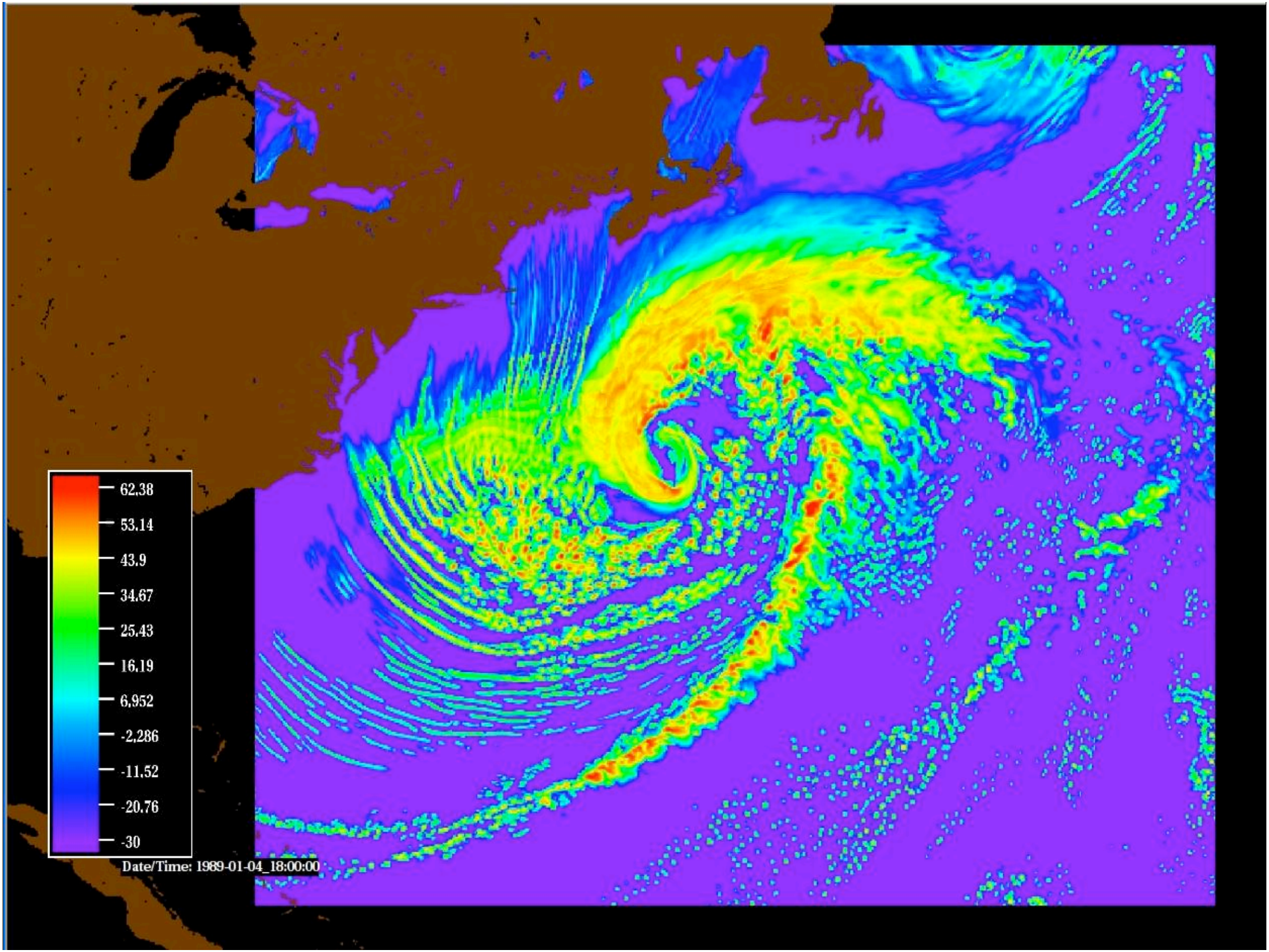
Precipitable Water (inches)

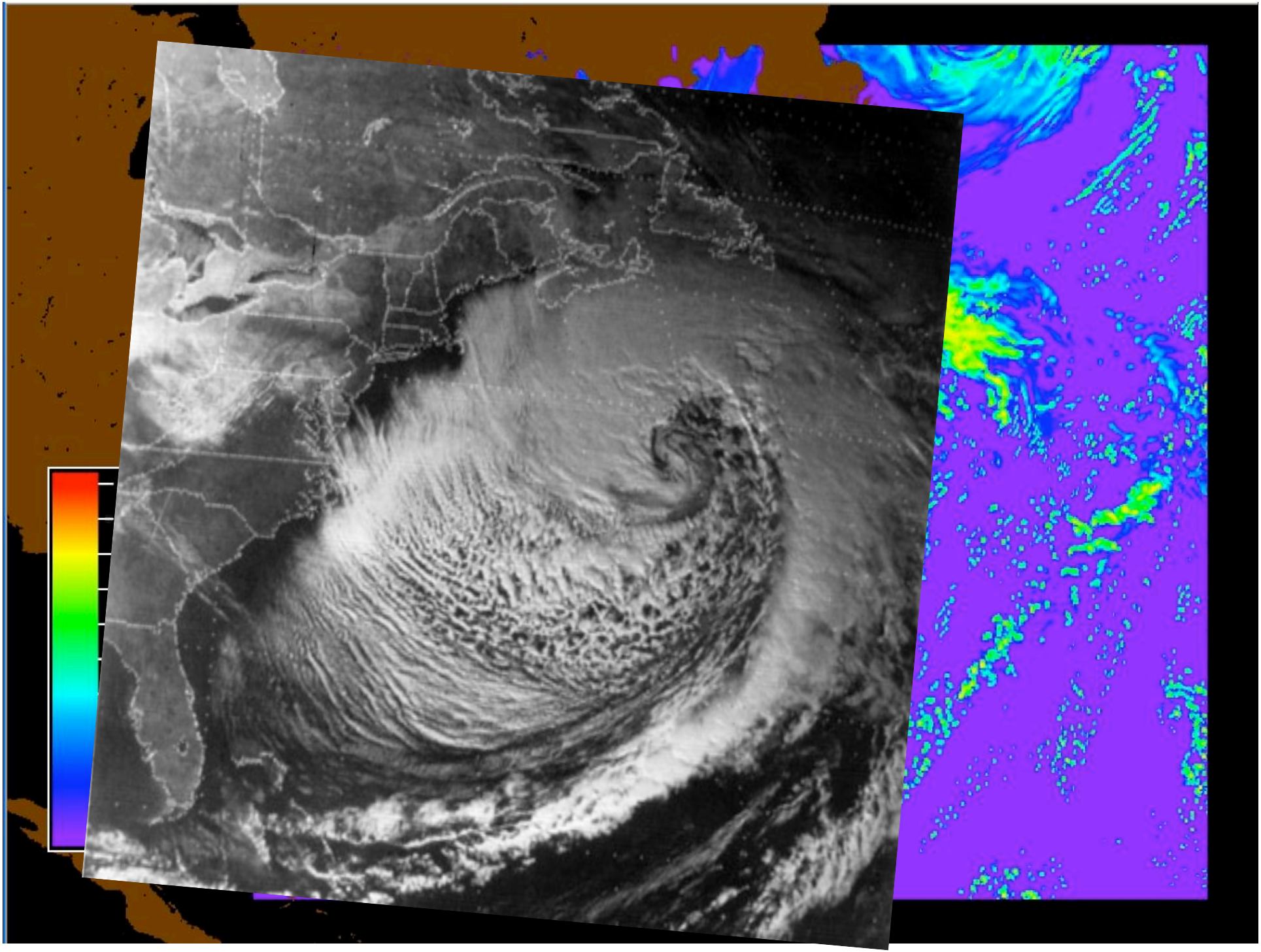


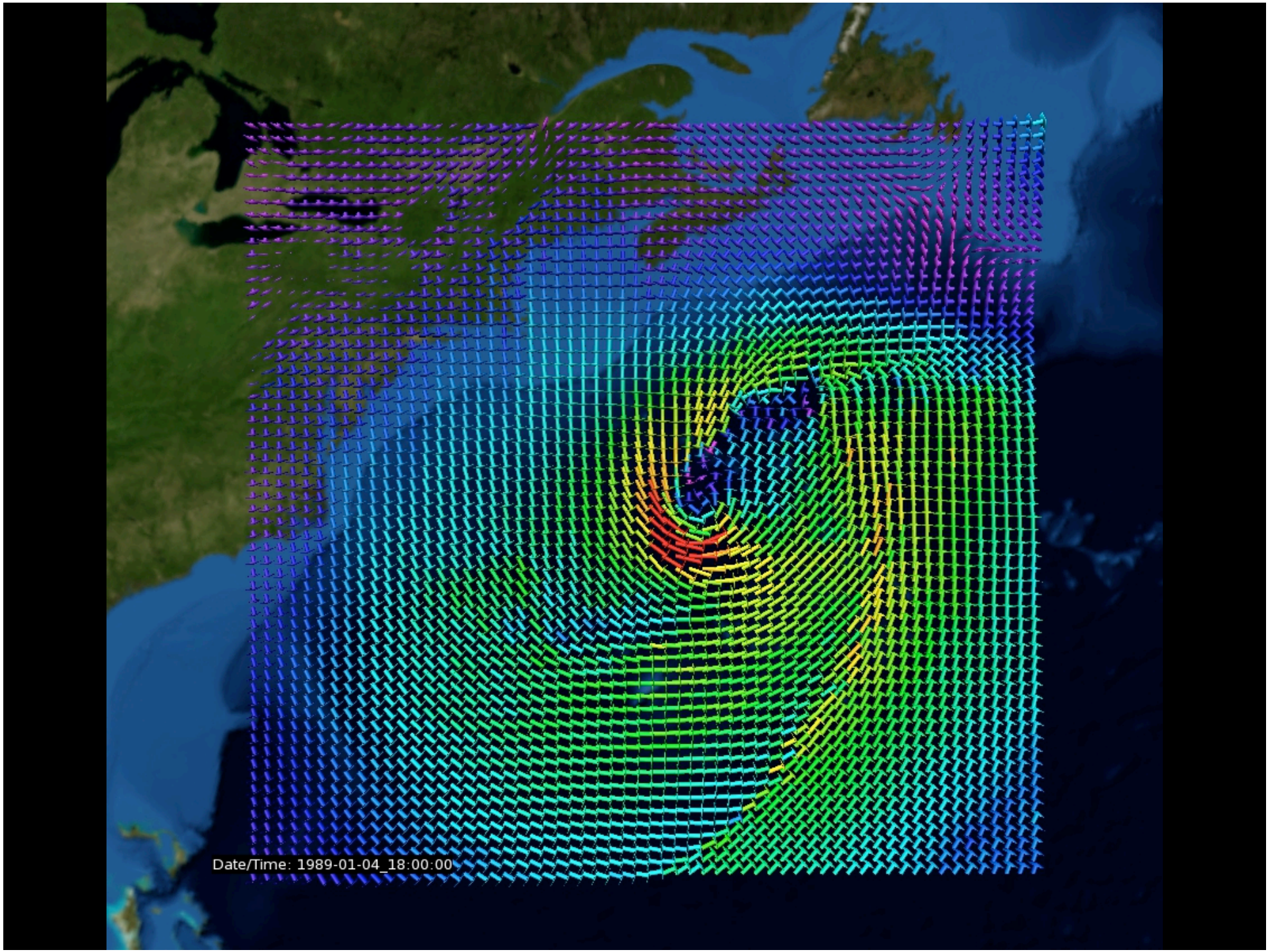
850-mb θ (K) and MSLP (mb)

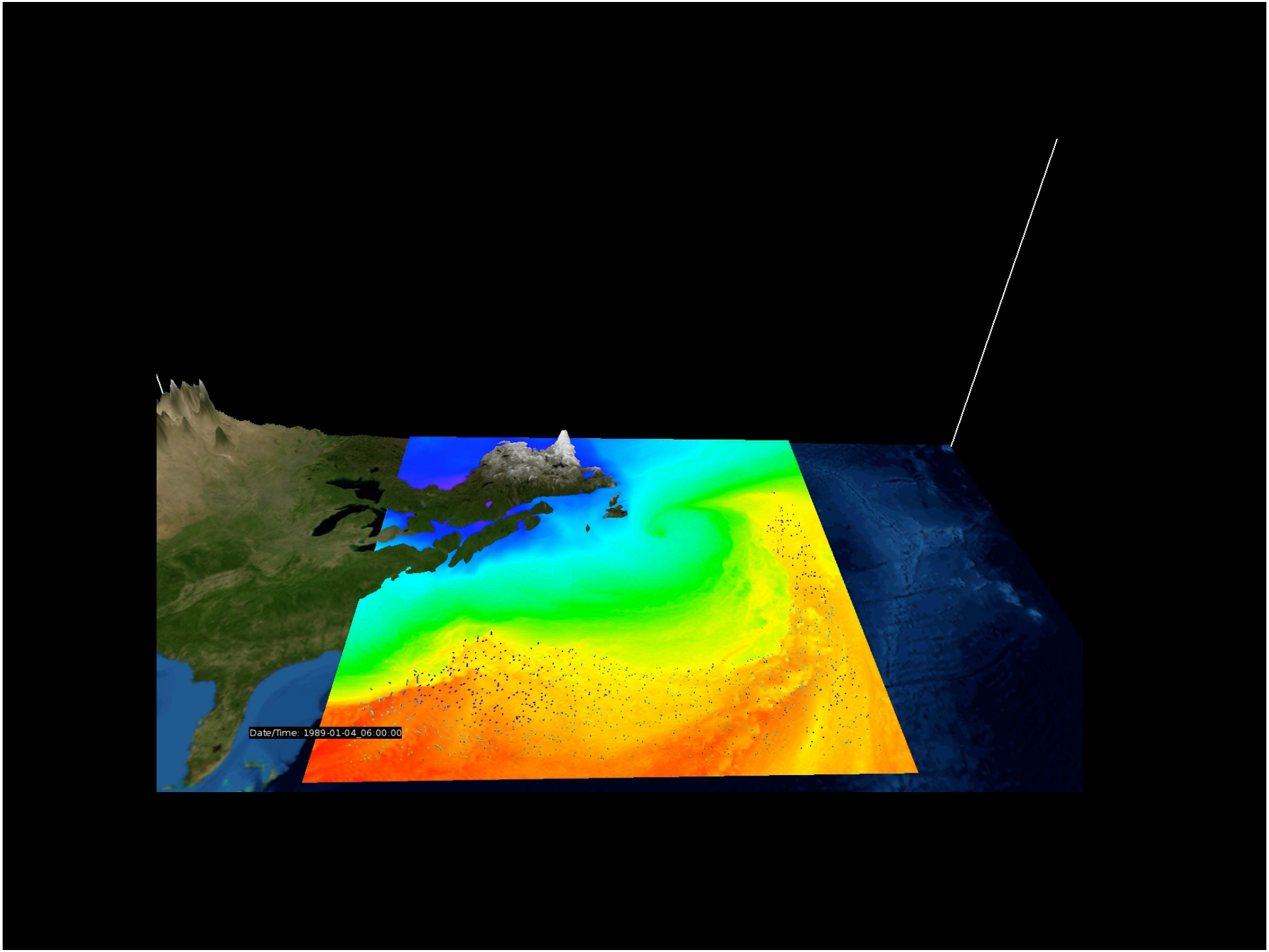



ERICA IOP- 4; 4 January 1989
WRF 18-h Forecast 4-km horizontal resolution forecast
Simulated radar reflectivity
62.38
53.14
43.9
34.67
25.43
16.19
6.952
-2.286
-11.52
-20.76
-30
Date/Time: 1989-01-04_18:00:00


62.38
53.14
43.9
34.67
25.43
16.19
6.952
-2.286
-11.52
-20.76
-30
Date/Time: 1989-01-04_18:00:00




Date/Time: 1989-01-04_18:00:00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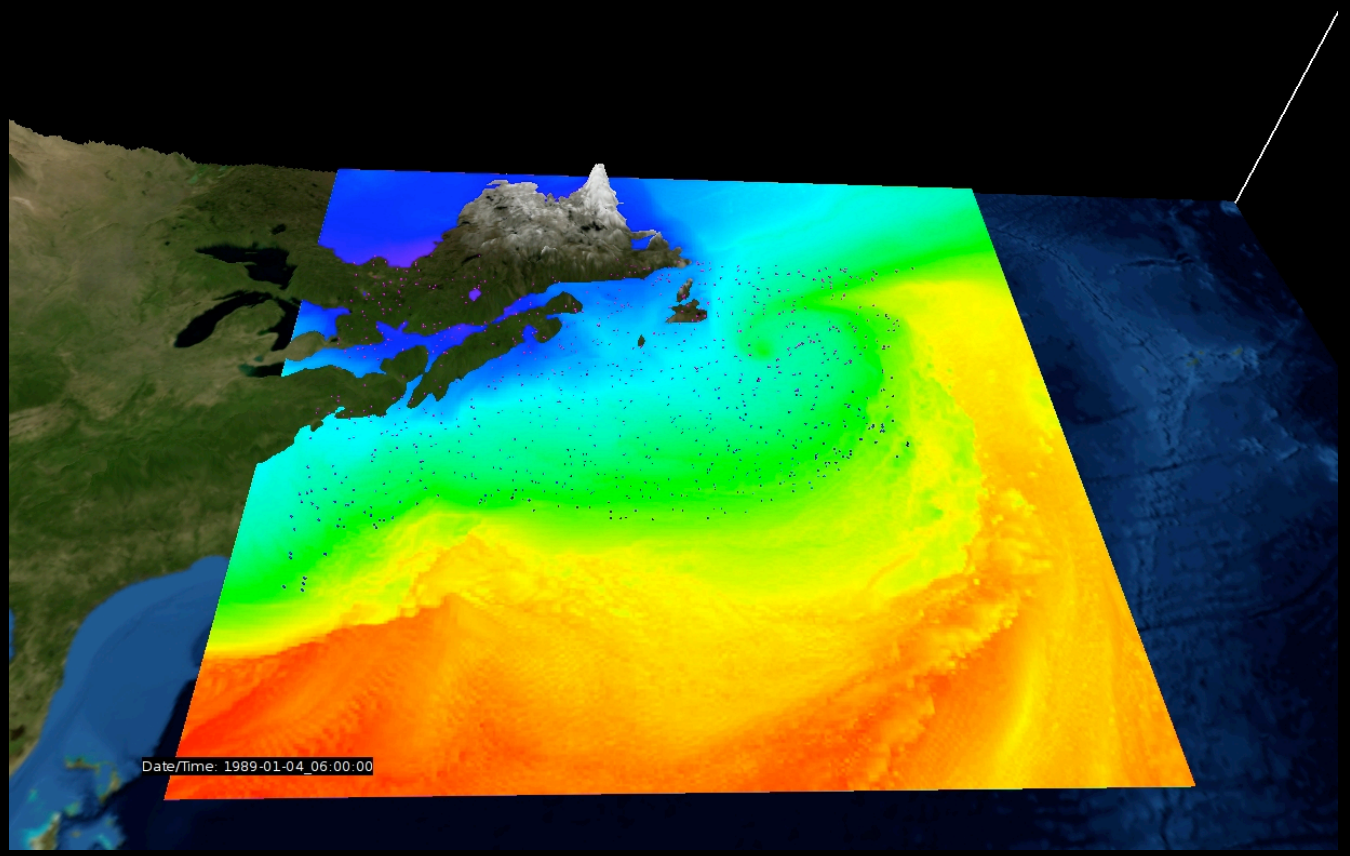
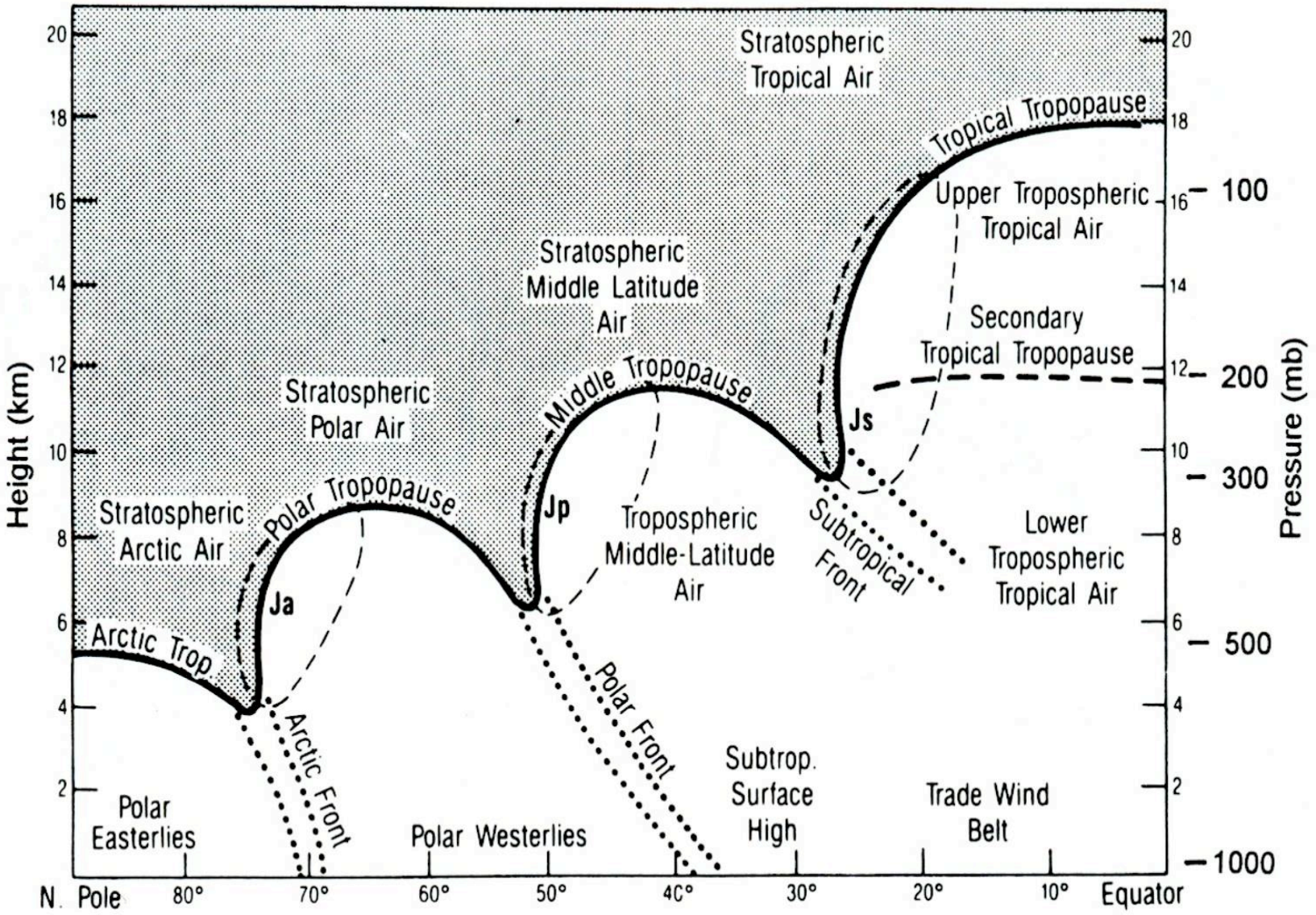
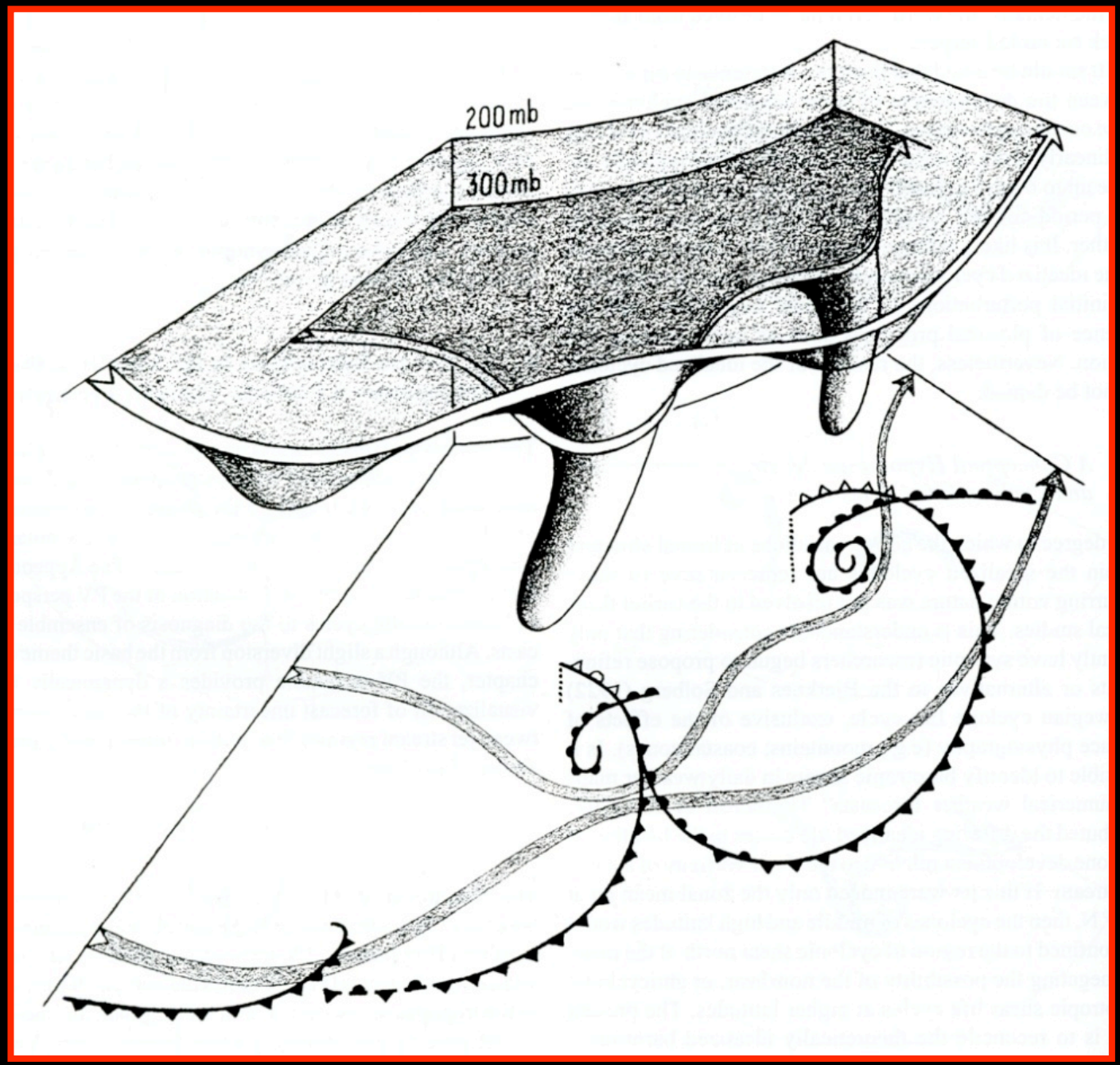
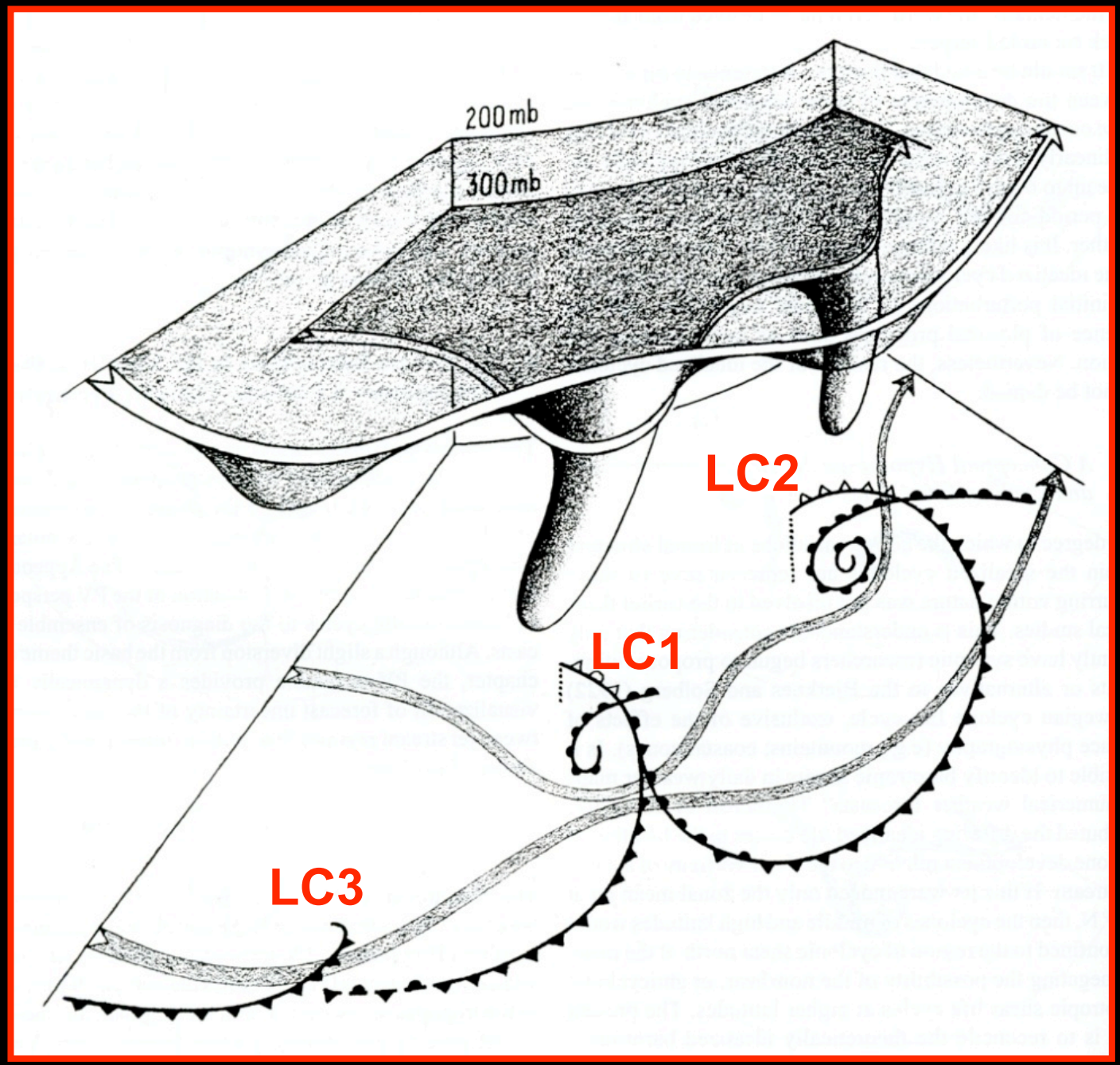

Date/Time: 1989-01-04_06:00:00

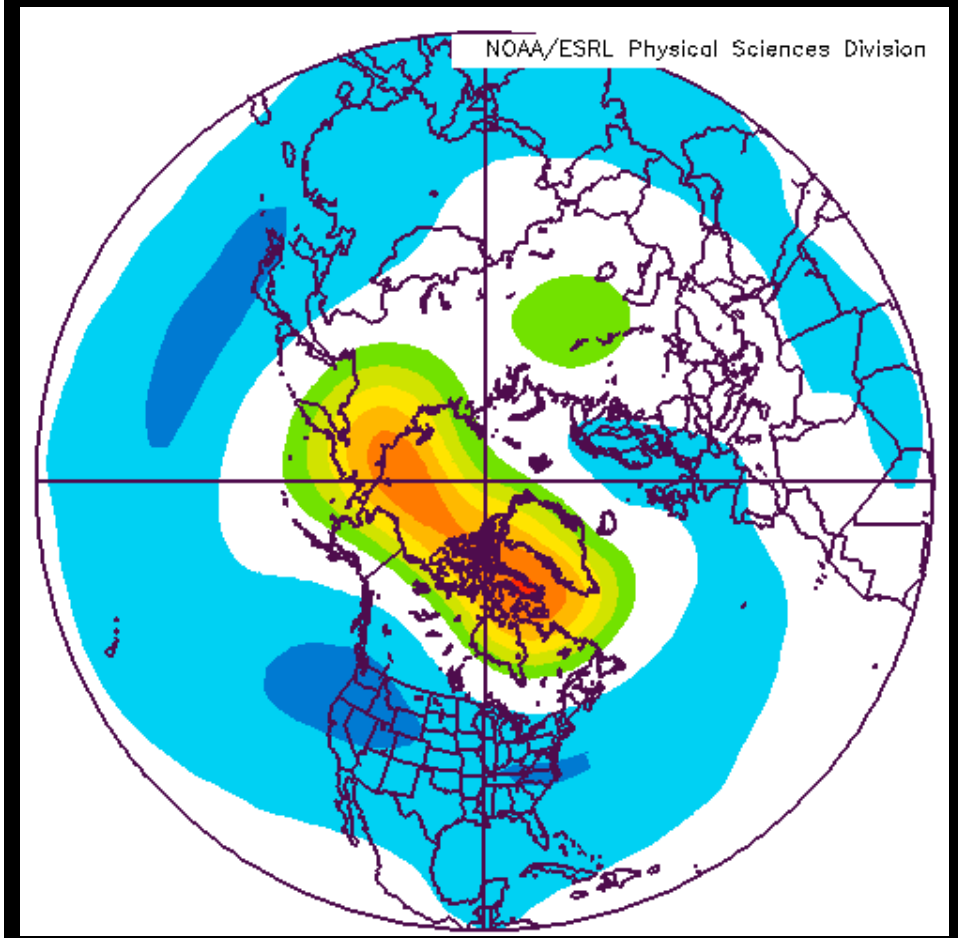

Stratospheric
Tropical Air
Tropical Tropopause
Upper Tropospheric
Tropical Air
Secondary
Tropical Tropopause
Stratospheric
Middle Latitude
Air
Middle Tropopause
Stratospheric
Polar Air
Polar Tropopause
Stratospheric
Arctic Air
Arctic Trop.
Ja
Jp
Js
Tropospheric
Middle-Latitude
Air
Subtropical
Front
Lower
Tropospheric
Tropical Air
Arctic Front
Polar Front
Subtrop.
Surface
High
Trade Wind
Belt
Polar
Easterlies
Polar Westerlies
N. Pole
80°
70°
60°
50°
40°
30°
20°
10°
Equator
Height (km)
Pressure (mb)
100
200
300
500
1000


200 mb
300 mb

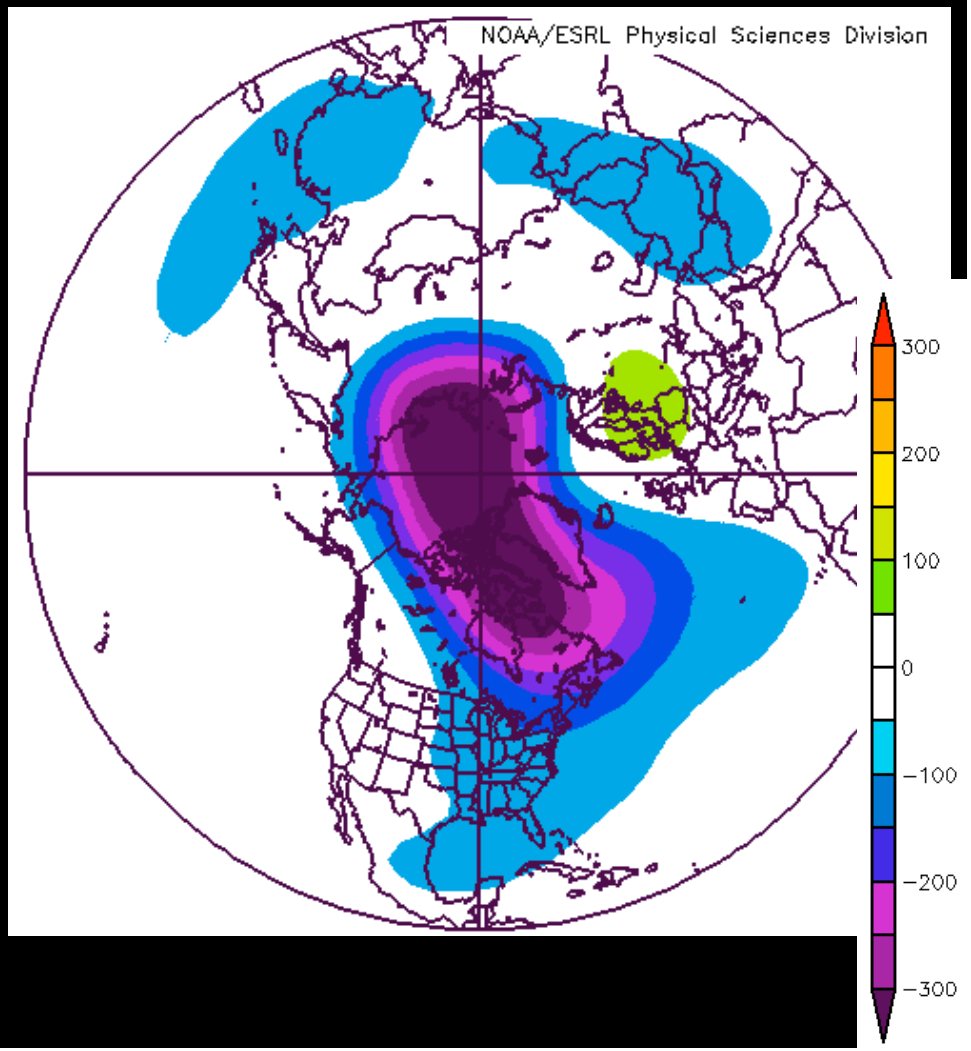

200 mb
300 mb
LC2
LC1
LC3

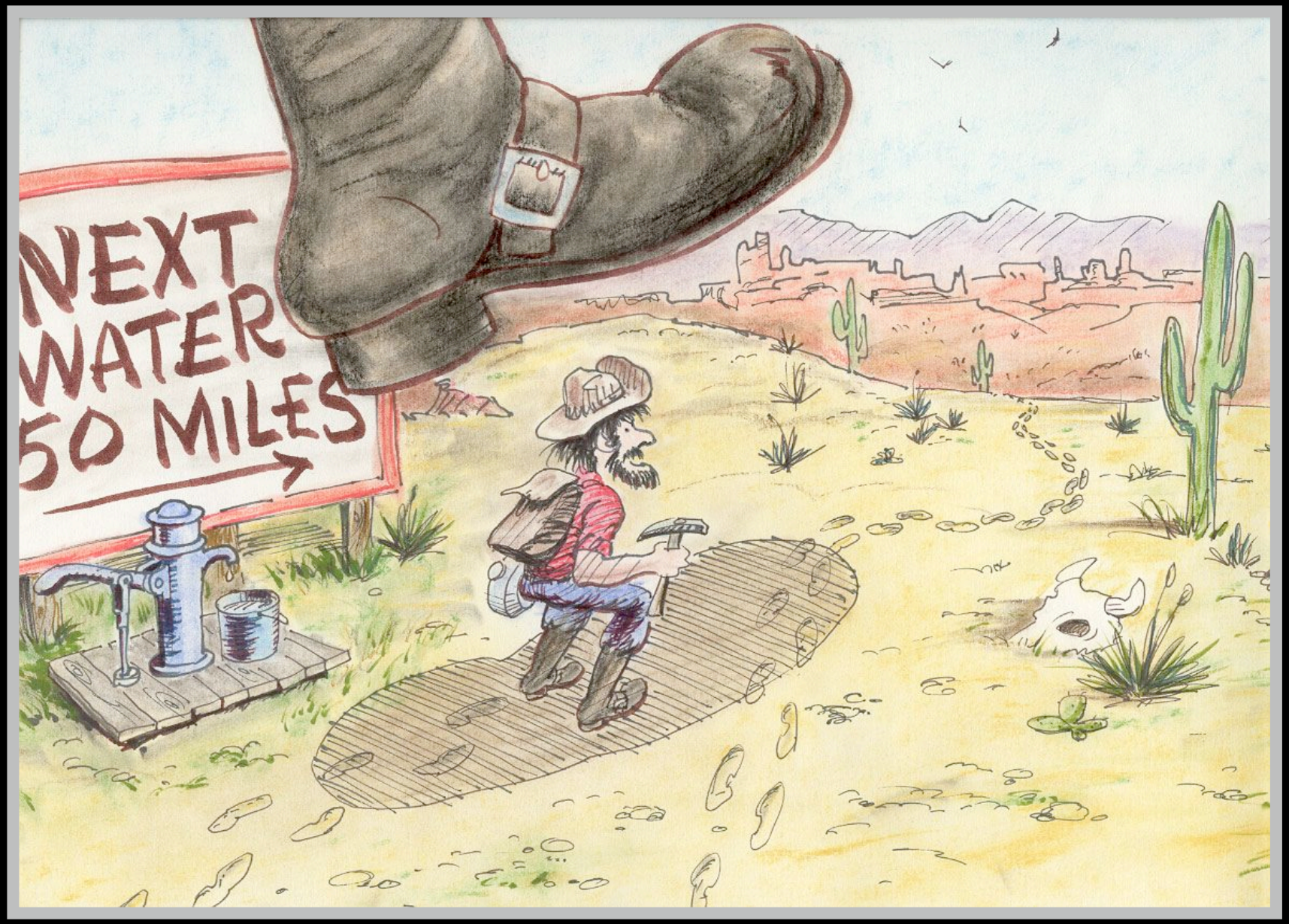
50-mb Height Anomaly (m)

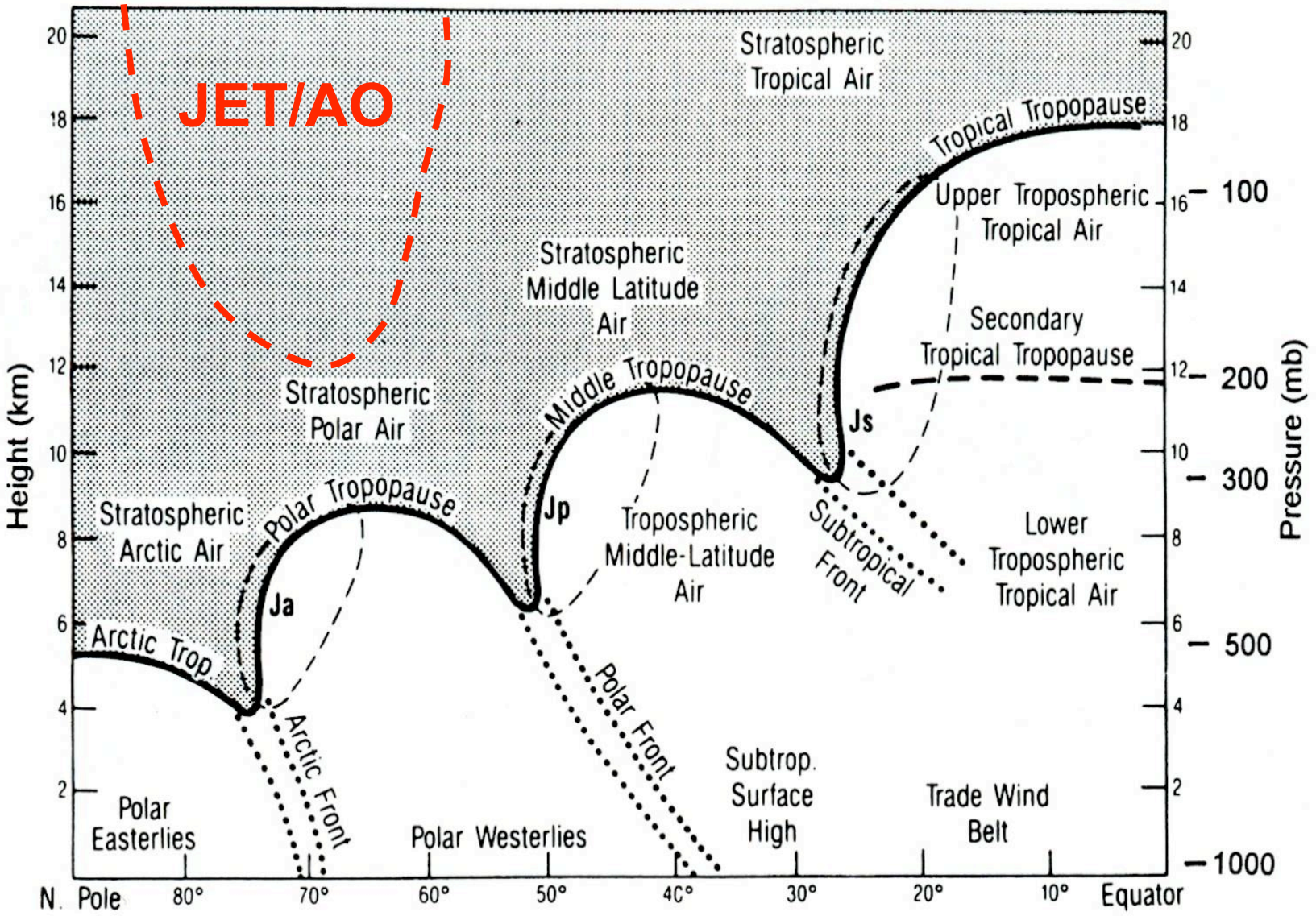
11 Dec 2010–15 Jan 2011 (AO−)



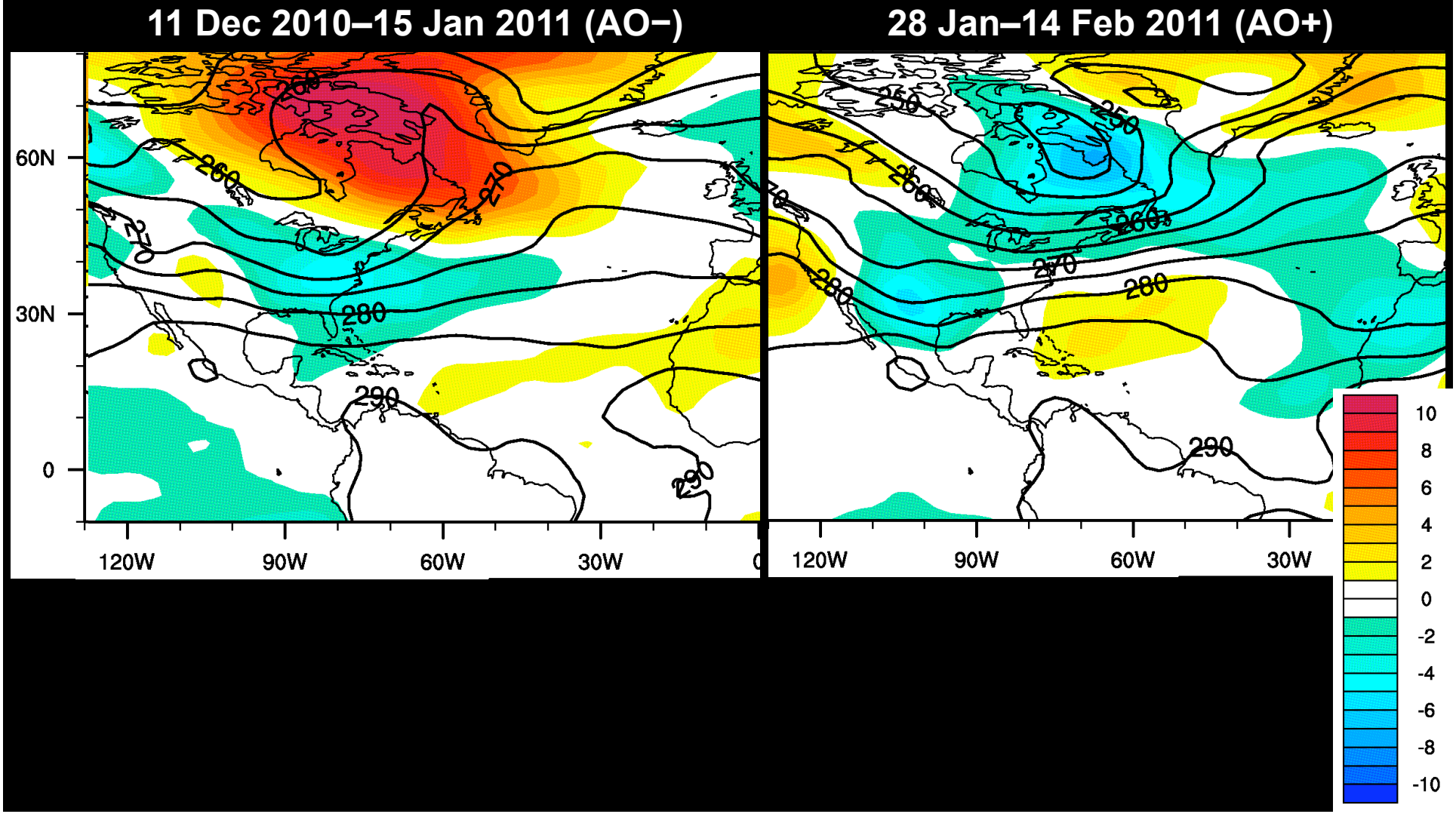
28 Jan–14 Feb 2011 (AO+)

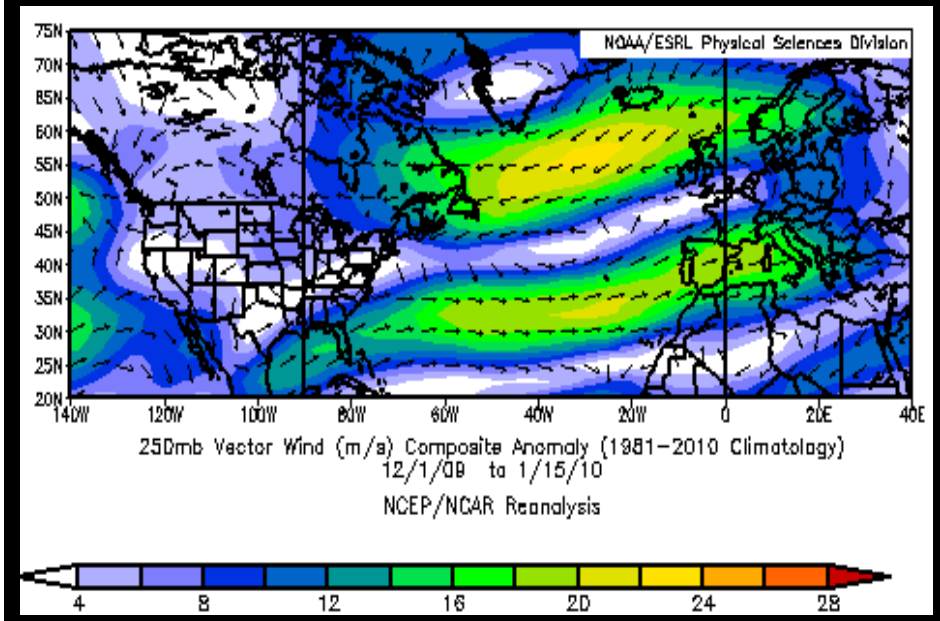


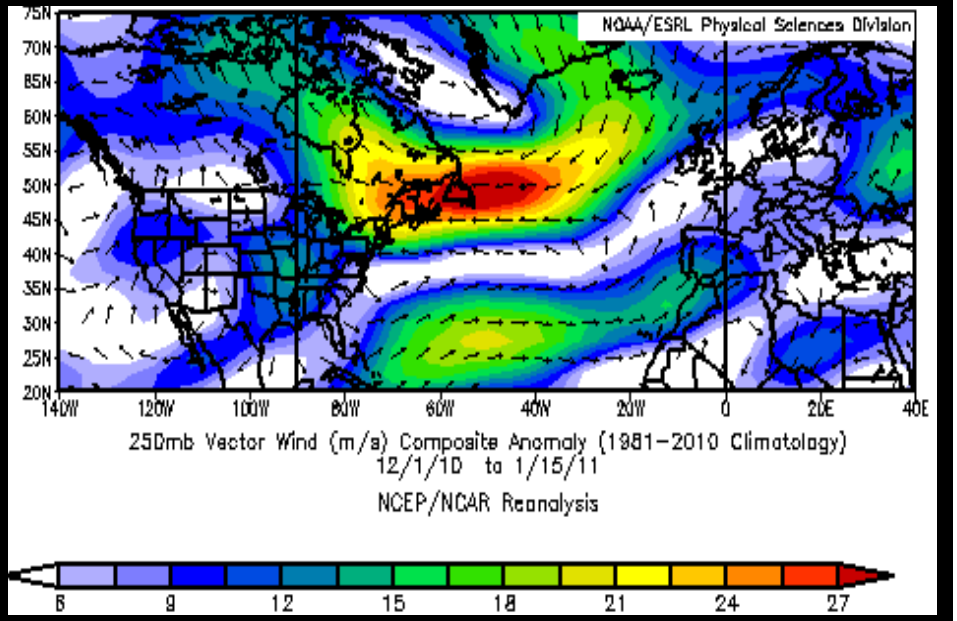

NEXT
WATER
50 MILES

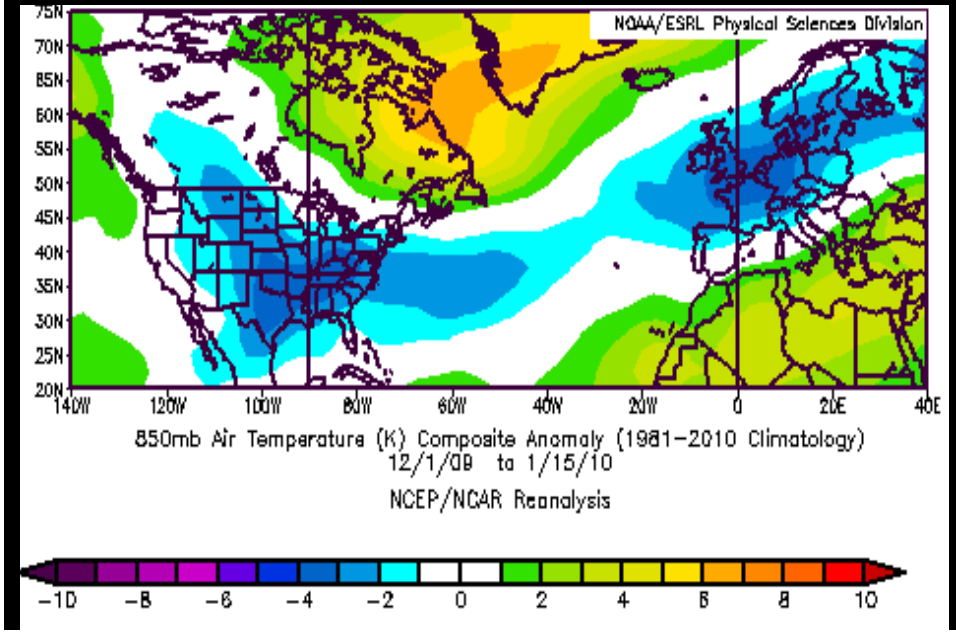

JET/AO
Stratospheric Tropical Air
Tropical Tropopause
Upper Tropospheric Tropical Air
Secondary Tropical Tropopause
Stratospheric Middle Latitude Air
Middle Tropopause
Stratospheric Polar Air
Js
Jp
Ja
Polar Tropopause
Stratospheric Arctic Air
Tropospheric Middle-Latitude Air
Subtropical Front
Lower Tropospheric Tropical Air
Arctic Trop.
Arctic Front
Polar Front
Subtrop. Surface High
Trade Wind Belt
Polar Easterlies
Polar Westerlies
N. Pole
80°
70°
60°
50°
40°
30°
20°
10°
Equator
Height (km)
Pressure (mb)
100
200
300
500
1000

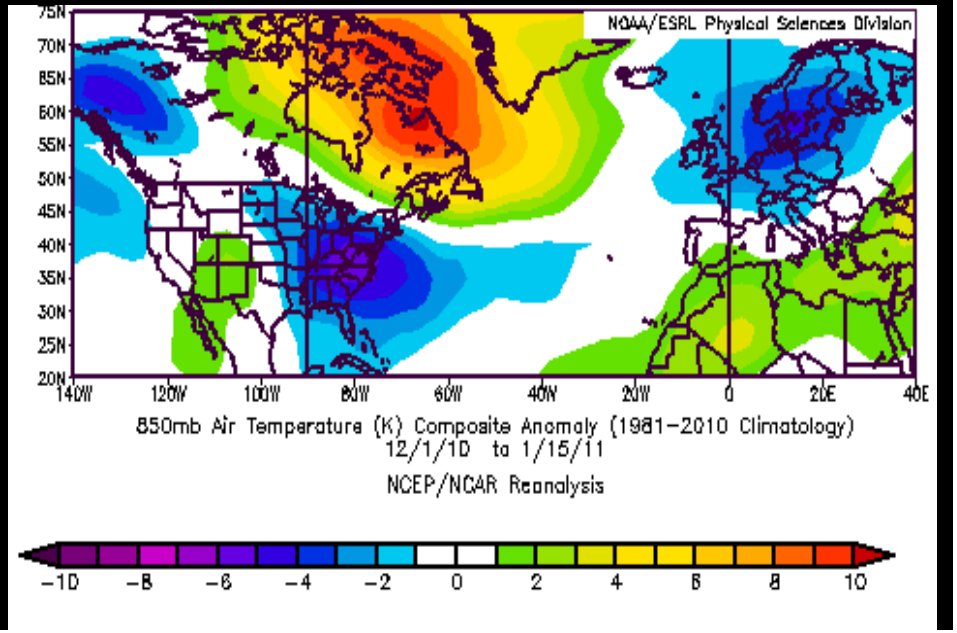
North Atlantic 850-mb Temperature Mean and Anomaly (K)




NOAA/ESRL Physical Sciences Division
75N
70N
65N
60N
55N
50N
45N
40N
35N
30N
25N
20N
140W
120W
100W
80W
60W
40W
20W
0
20E
40E
250mb Vector Wind (m/s) Composite Anomaly (1981-2010 Climatology)
12/1/09 to 1/15/10
NCEP/NCAR Reanalysis
4
8
12
16
20
24
28


NOAA/ESRL Physical Sciences Division
75N
70N
65N
60N
55N
50N
45N
40N
35N
30N
25N
20N
140W
120W
100W
80W
60W
40W
20W
0
20E
40E
250mb Vector Wind (m/s) Composite Anomaly (1981-2010 Climatology)
12/1/10 to 1/15/11
NCEP/NCAR Reanalysis
6
9
12
15
18
21
24
27


NOAA/ESRL Physical Sciences Division
75N
70N
65N
60N
55N
50N
45N
40N
35N
30N
25N
20N
140W
120W
100W
80W
60W
40W
20W
0
20E
40E
850mb Air Temperature (K) Composite Anomaly (1981-2010 Climatology)
12/1/09 to 1/15/10
NCEP/NCAR Reanalysis
-10
-8
-6
-4
-2
0
2
4
6
8
10


NOAA/ESRL Physical Sciences Division
75N
70N
65N
60N
55N
50N
45N
40N
35N
30N
25N
20N
140W
120W
100W
80W
60W
40W
20W
0
20E
40E
850mb Air Temperature (K) Composite Anomaly (1981-2010 Climatology)
12/1/10 to 1/15/11
NCEP/NCAR Reanalysis
-10
-8
-6
-4
-2
0
2
4
6
8
10