The Impact of MODIS-derived Polar Winds on Global Forecasts

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Outline

- Motivation
- Data: MODIS Polar Winds
- Impact of MODIS winds in model forecasts
- How polar-only data affects lower-latitude weather systems

Motivation

Feature-tracked winds derived from a time sequence of MODIS satellite imagery over the polar regions are routinely input into many operational global numerical models. These NWP centers report that the winds have a positive impact on forecasts not only in the polar regions, but also into middle- and lower-latitudes, especially in 3- to 5-day forecasts and forecast bust situations.

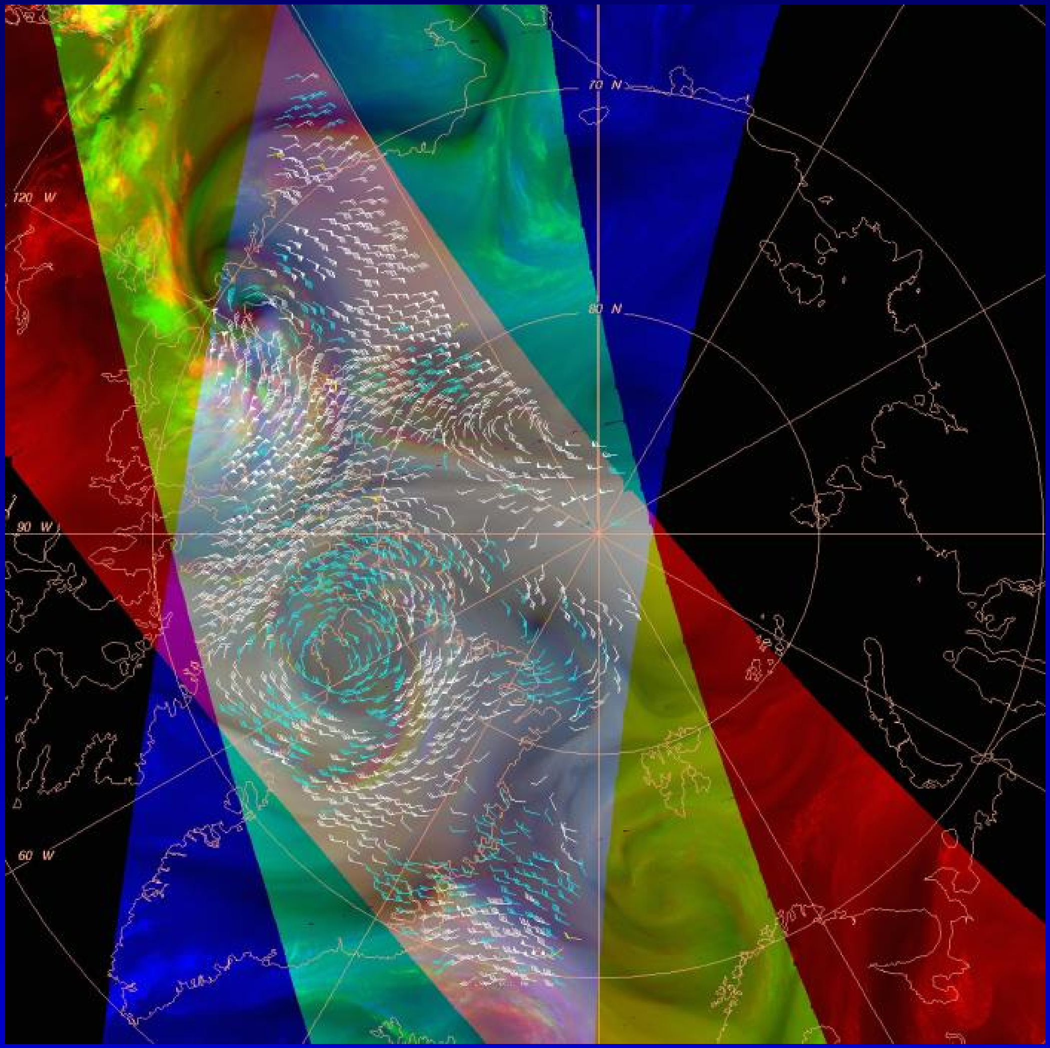
The MODIS winds are only derived poleward of 65 degrees latitude. What are possible explanations for this <u>global</u> impact?

Considerations:

1. Assimilation
2. Dynamics near the jet stream

The Data

Unlike geostationary satellites at lower latitudes, it is not be possible to obtain complete polar coverage at a snapshot in time with one or two polar-orbiters. Instead, winds must be derived for areas that are covered by two or three successive orbits, an example of which is shown here. The gray area is the overlap between three orbits.



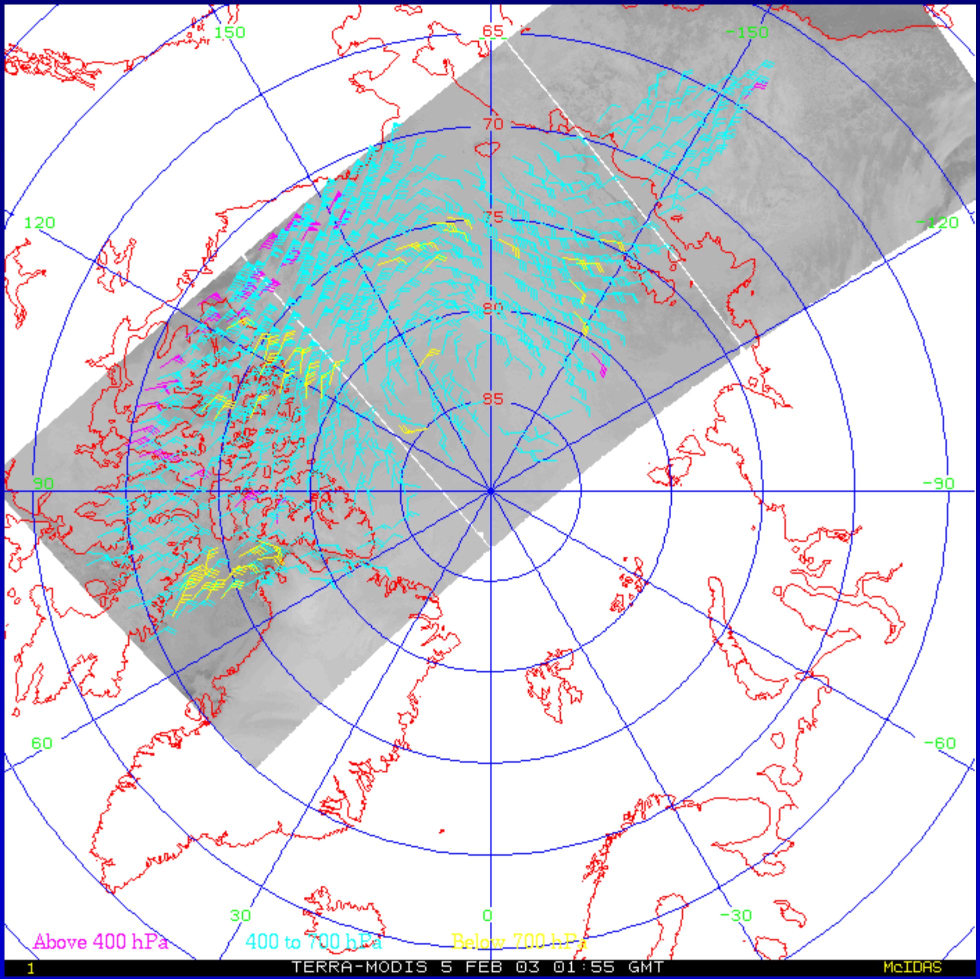
Three overlapping Aqua MODIS passes, with WV and IR winds superimposed. The white wind barbs are above 400 hPa, cyan are 400 to 700 hPa, and yellow are below 700 hPa.

The Data

Cloud and water vapor features are tracked from successive triplets of Terra and Aqua MODIS passes over the polar regions.

The majority of the vectors are in the upper troposphere.

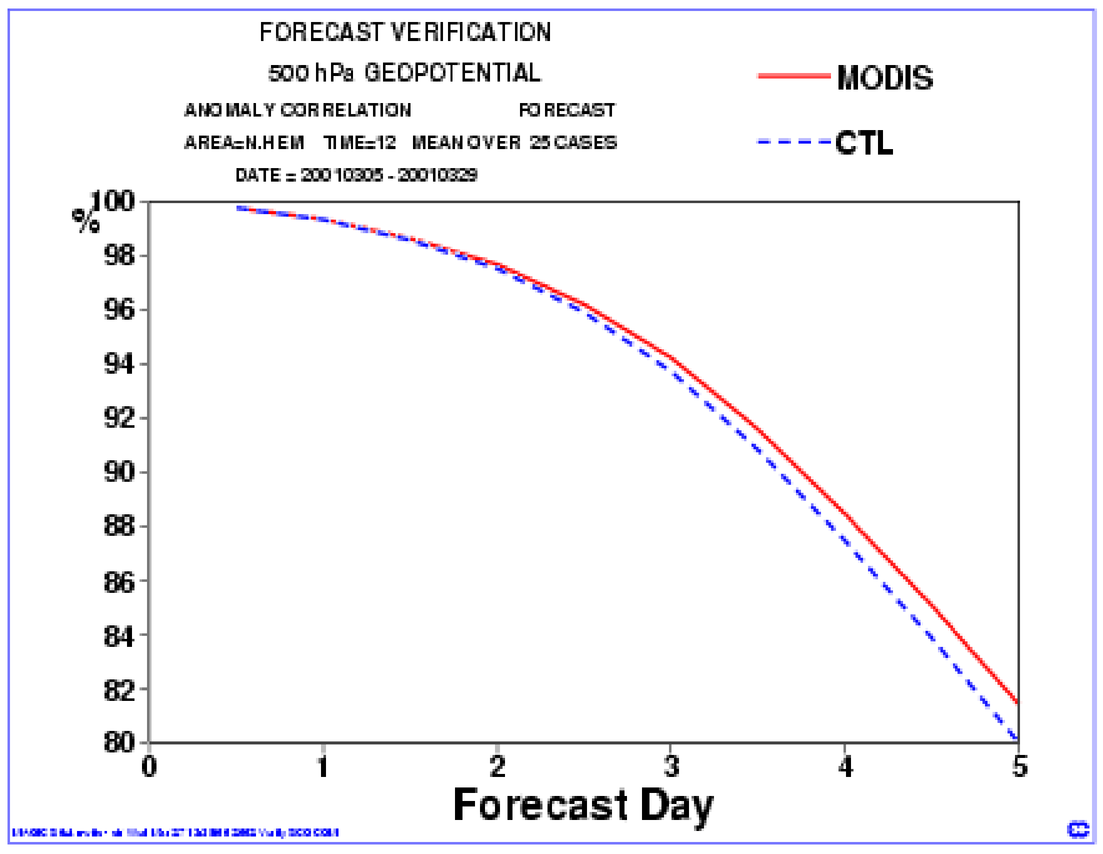
One Day of Arctic Orbits from Terra



All winds over MODIS band 31 (11 µm) image

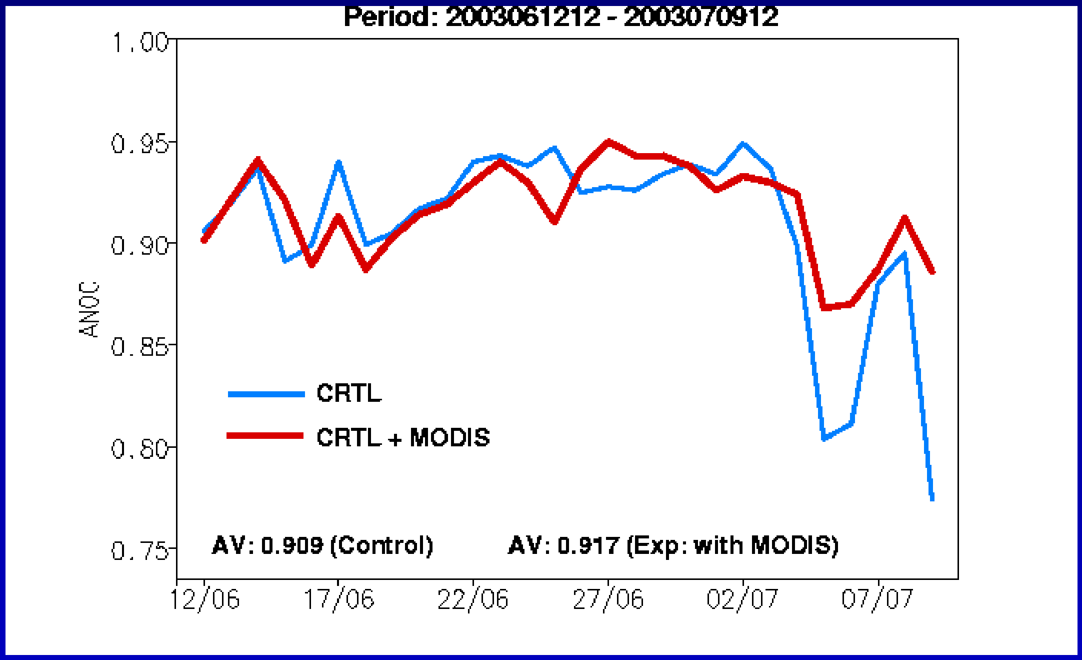
ECMWF Model Impact: N. Hemisphere

ACC as a function of forecast day for the geopotential at 500 hPa. Study period is 5-29 March 2001. The correlation is between the forecast geopotential height anomalies, with and without the MODIS winds, and their own analyses. This is for the Northern Hemisphere, which is defined as north of 20 degrees latitude..



DWD Model Impact: Daily ACC

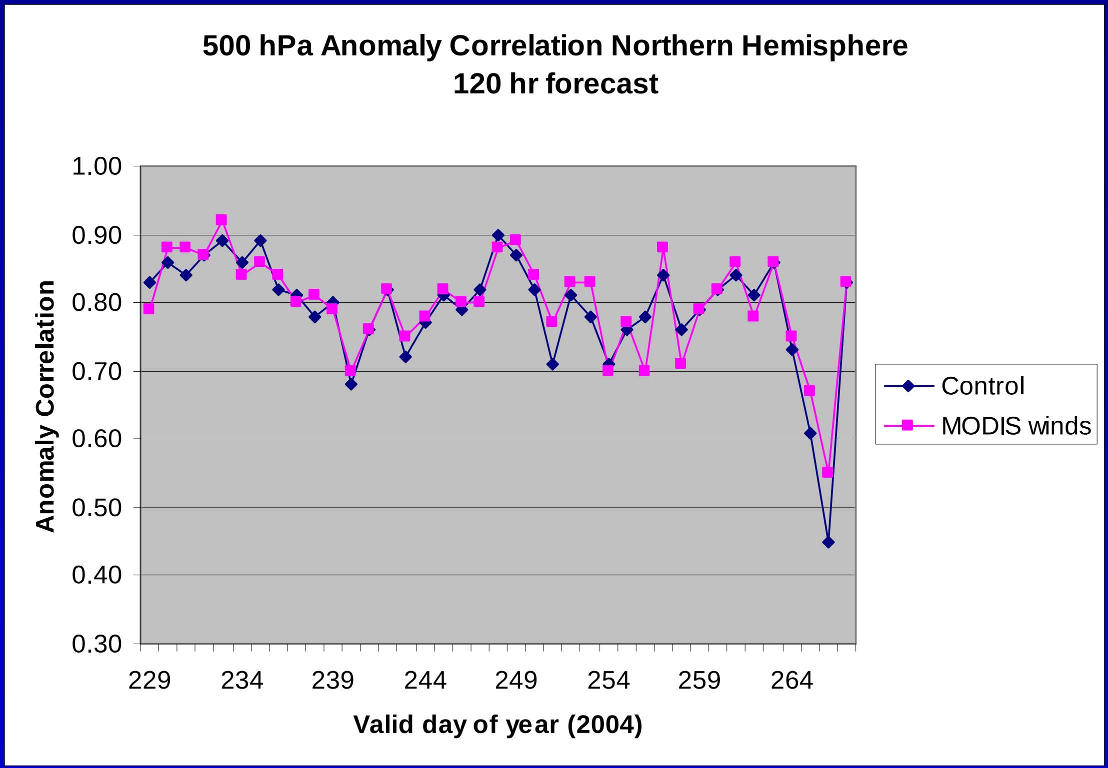
ACC as a function of day for the 60-hour forecast of the geopotential at 500 hPa. Study period is 12 June to 9 July 2003. Forecast scores are the correlation between the forecast geopotential height anomalies, with and without the MODIS winds, and their own analyses. This is for the Northern Hemisphere.



From Alexander Cress at the 7th Int. Winds Workshop

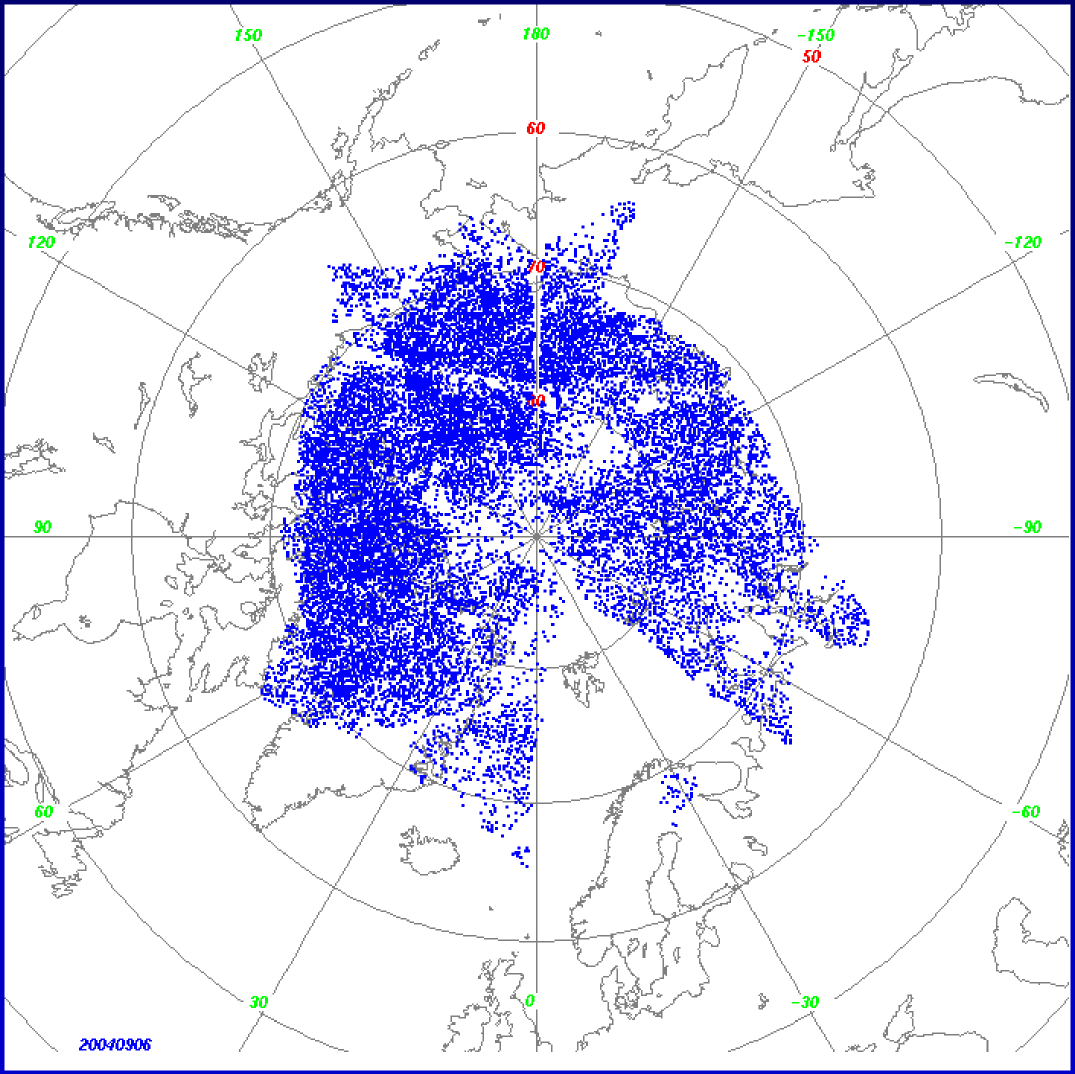
The Experiment

Model runs consisting of a control and continuously-assimilated MODIS winds are run for six weeks beginning on 10 Aug 2004. This used a pre-operational version of NCEP's GFS model. Model resolution of T254 with 64 layers.



The Experiment

MODIS wind coverage for the 0000 GMT assimilation cycle on 06 September 2004. There are about 21,300 winds at this time: +/- 3 hours from model run time, arriving by 6 hours after the synoptic time.



Mechanisms that Propagate Wind Information to Lower Latitudes

- Data assimilation
- Dynamics near the jet stream
  - Zonal phase speed of synoptic-scale Rossby waves
  - Ageostrophic wind relationship to wave propagation

Data Assimilation

The effect of the MODIS winds on the GFS analyses may be due, in part, to factors inherent in the assimilation system (GDAS):

- Dynamic bias correction for the satellite radiances:
  - Accounts for systematic errors
  - MODIS winds may affect satellite radiance bias correction
- Spectral assimilation
  - All data interpolated globally; evident in poorly observed areas.
  - Independent initialization: correct mass and temperature imbalance.
- Gravity waves

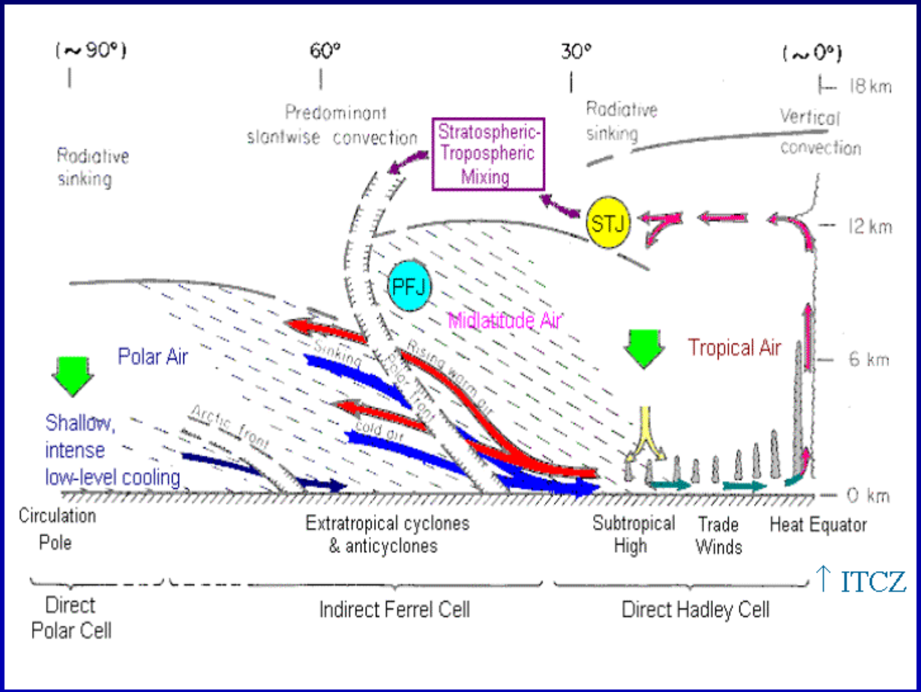
These can spread throughout the entire domain very quickly.

Dynamics near the Jet Stream

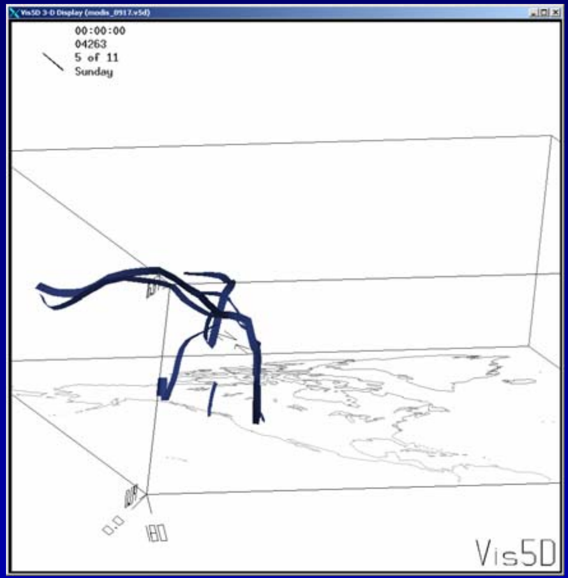
The MODIS are winds are derived in an area generally poleward of the polar jet streams, where conventional weather observations are relatively scarce. Tracking cloud and water vapor features provides predominantly upper-troposphere wind information.

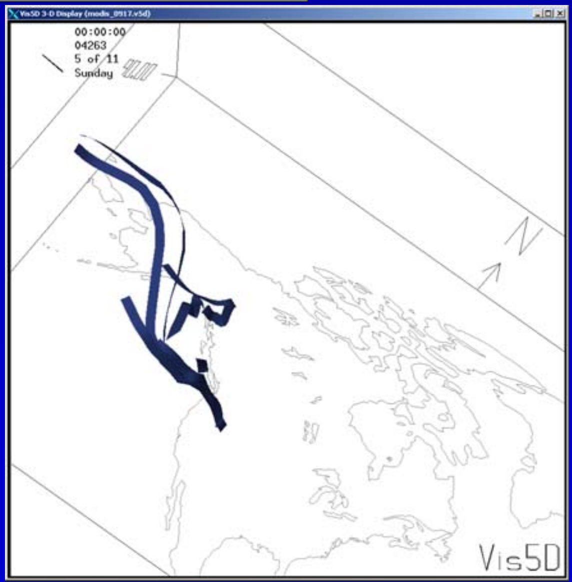
The winds measured are the true winds (including the ageostrophic component). This is unlike sounder winds which are in thermal, geostrophic balance.

Effects to Middle Latitudes



Meridional cross-section from the equator to the pole (Palmén and Newton, 1969)





Trajectories originating in Siberia that arrive in the western US in about 48 hours, descending from about 8-9 km to the surface. GFS forecast from 17 September 2004.

Ageostrophic wind

When the MODIS winds are assimilated, a mass adjustment takes place which results in changes in the height and wind field in the model atmosphere. This results in changes to the geostrophic and ageostrophic wind.

Geostrophic wind

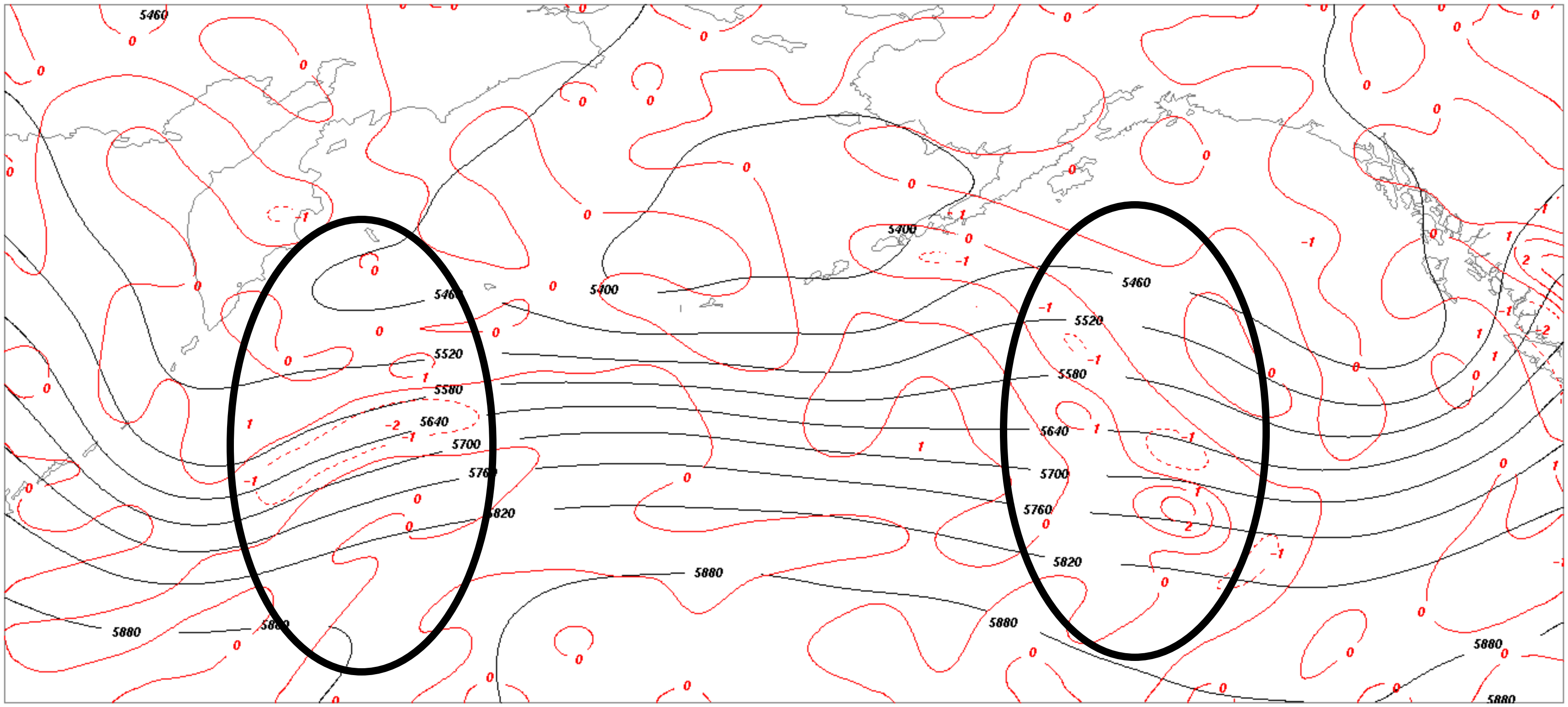
$$V_g \equiv f_0^{-1} k \times \nabla_p \Phi$$

Ageostrophic wind

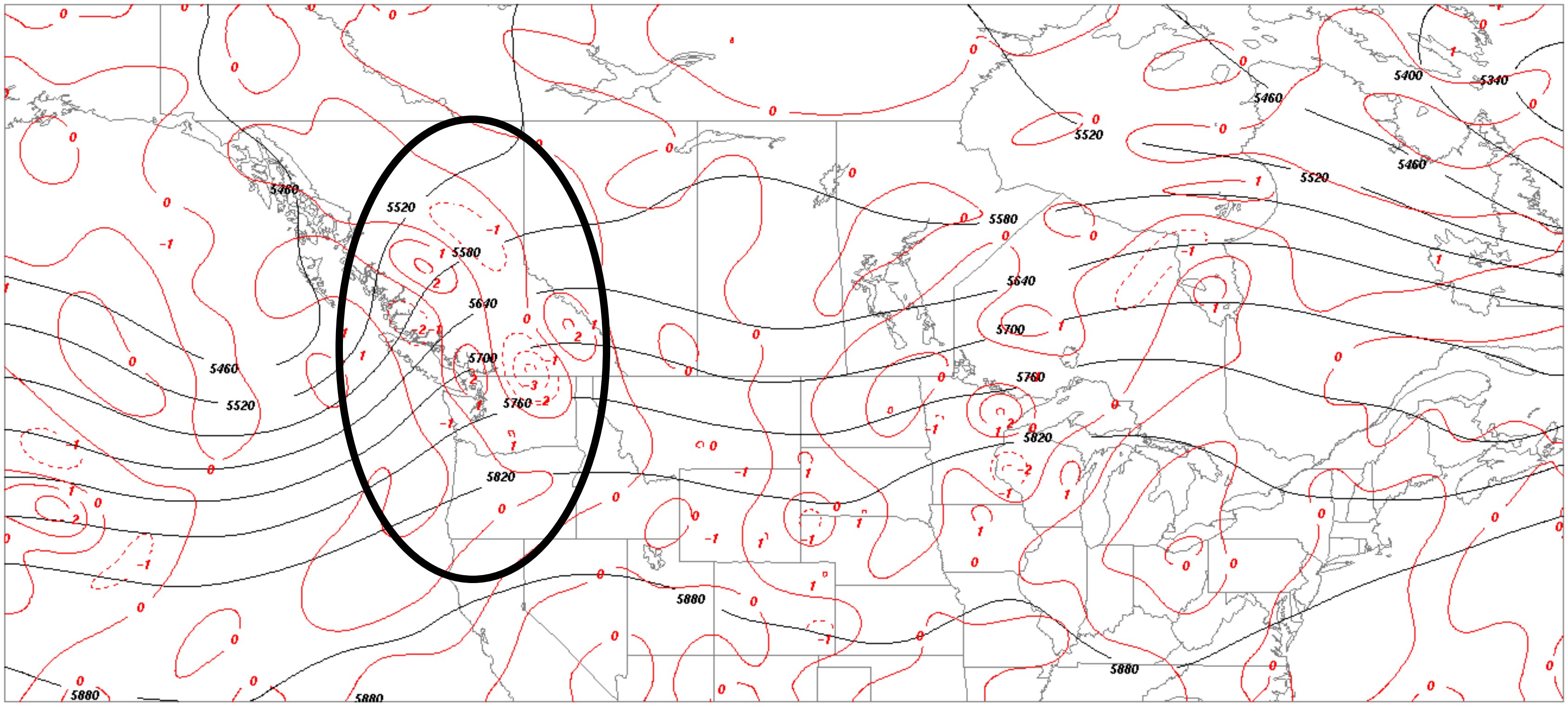
$$\vec{V}_a = \frac{1}{f_0}\hat{k} \times \frac{D_g \vec{V}_g}{Dt} = \frac{1}{f_0}\left[\hat{k} \times \frac{\partial \vec{V}_g}{\partial t} + \hat{k} \times \left(\vec{V}_g \bullet \nabla\right)\vec{V}_g\right]$$

Divergence of Ageostrophic wind

$$\nabla \bullet \vec{V}_a = -\frac{1}{f_0}\vec{V}_g \bullet \nabla \zeta_g$$



Difference in the divergence of the ageostrophic wind (10^{-5} s^{-1}) at 500 hPa between the MODIS winds and control model runs. Largest differences circled. This is the analysis at 0000 GMT on 11 September 2004.



091100 MODIS: 500 hPa heights, Diff of ageo divergence

Difference in the divergence of the ageostrophic wind (10^{-5} s^{-1}) at 500 hPa between the MODIS winds and control model runs. Largest difference circled. This is the analysis at 0000 GMT on 11 September 2004.

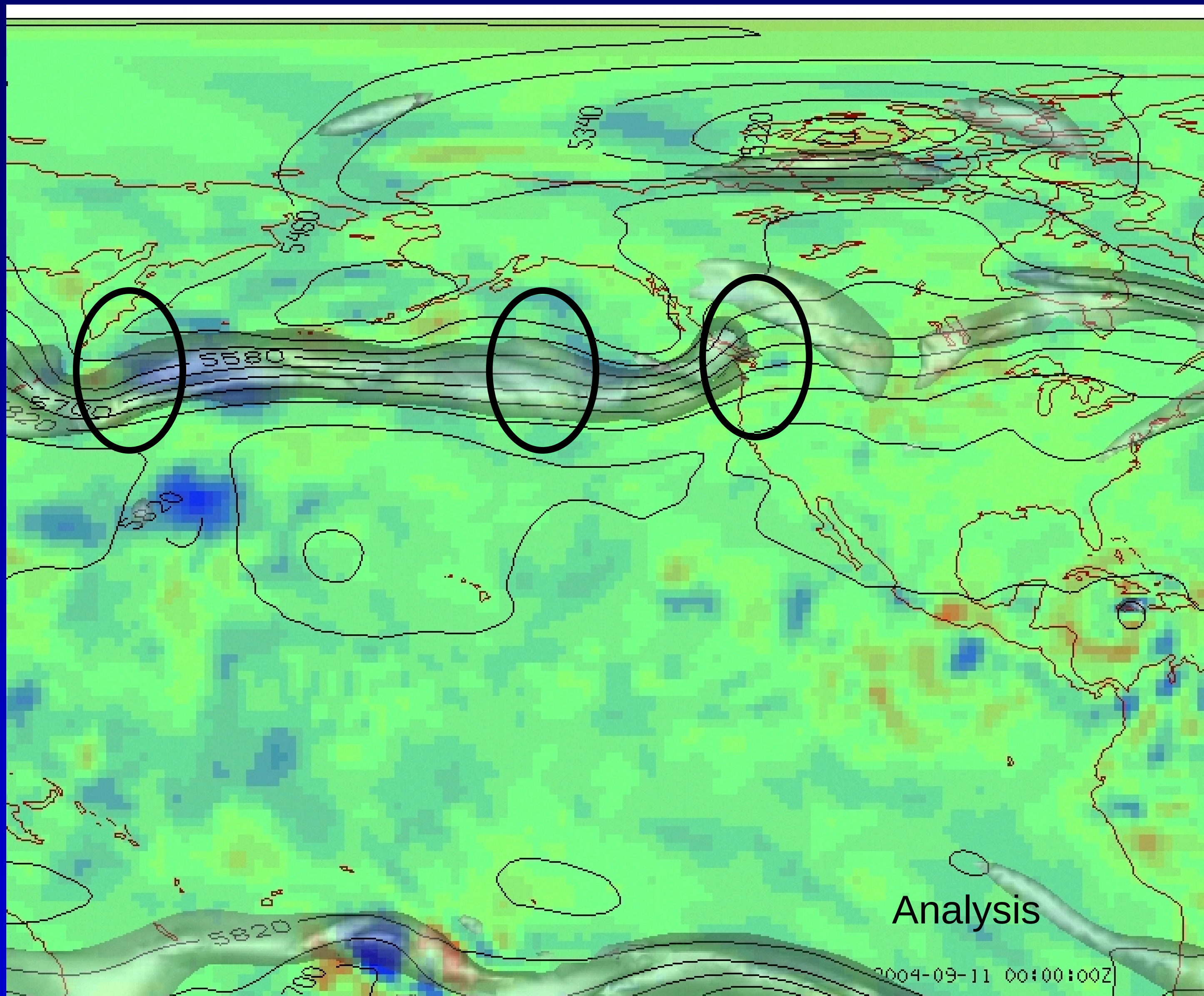
Forecast impact: Thickness

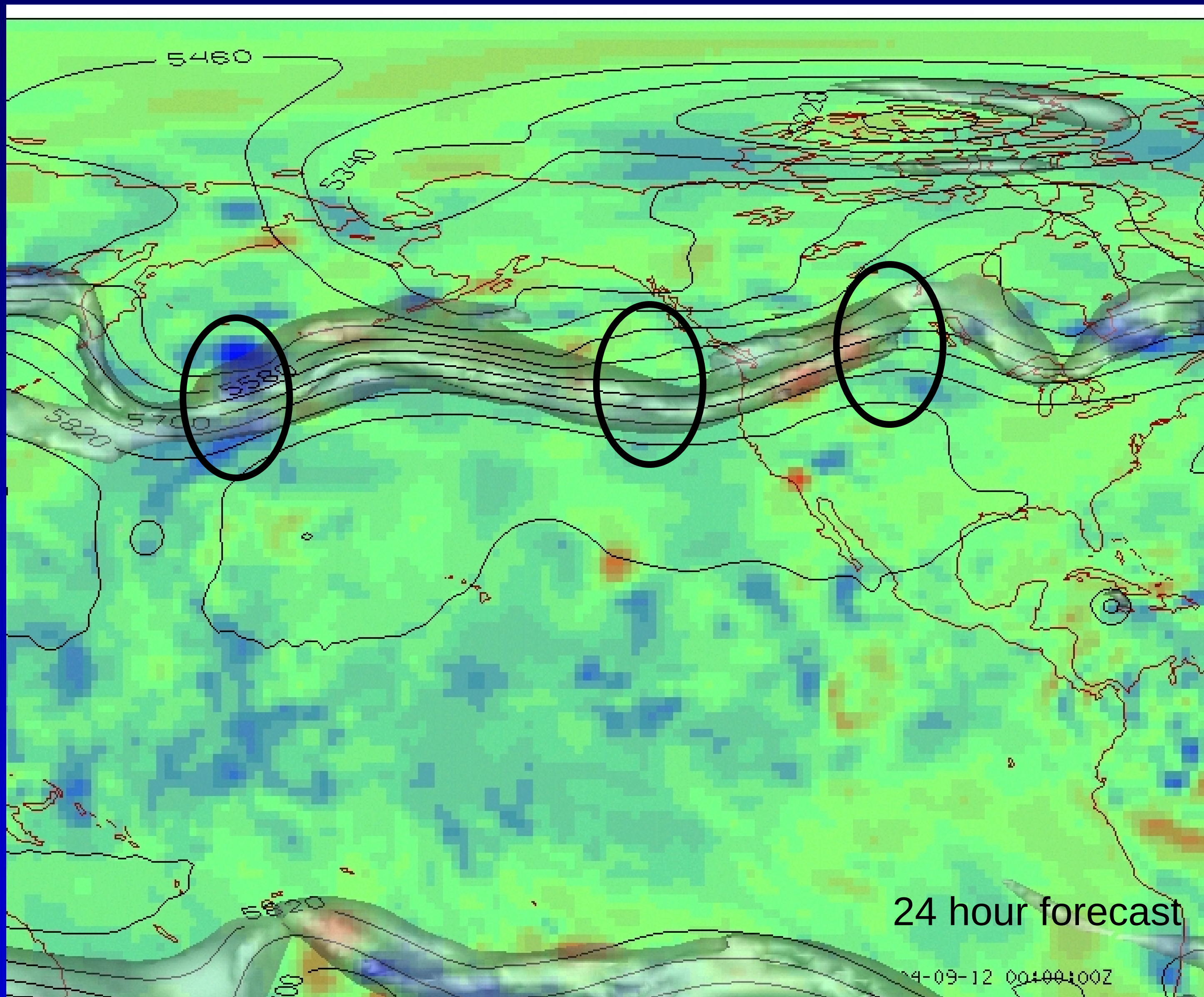
The following 6 slides are the analysis through the 120 hour forecast showing differences in the 1000-500 hPa thickness (MODIS-control), along with the MODIS 500 hPa heights. The color represents -30 (blue) to +30 (red) gpm difference of the thickness.

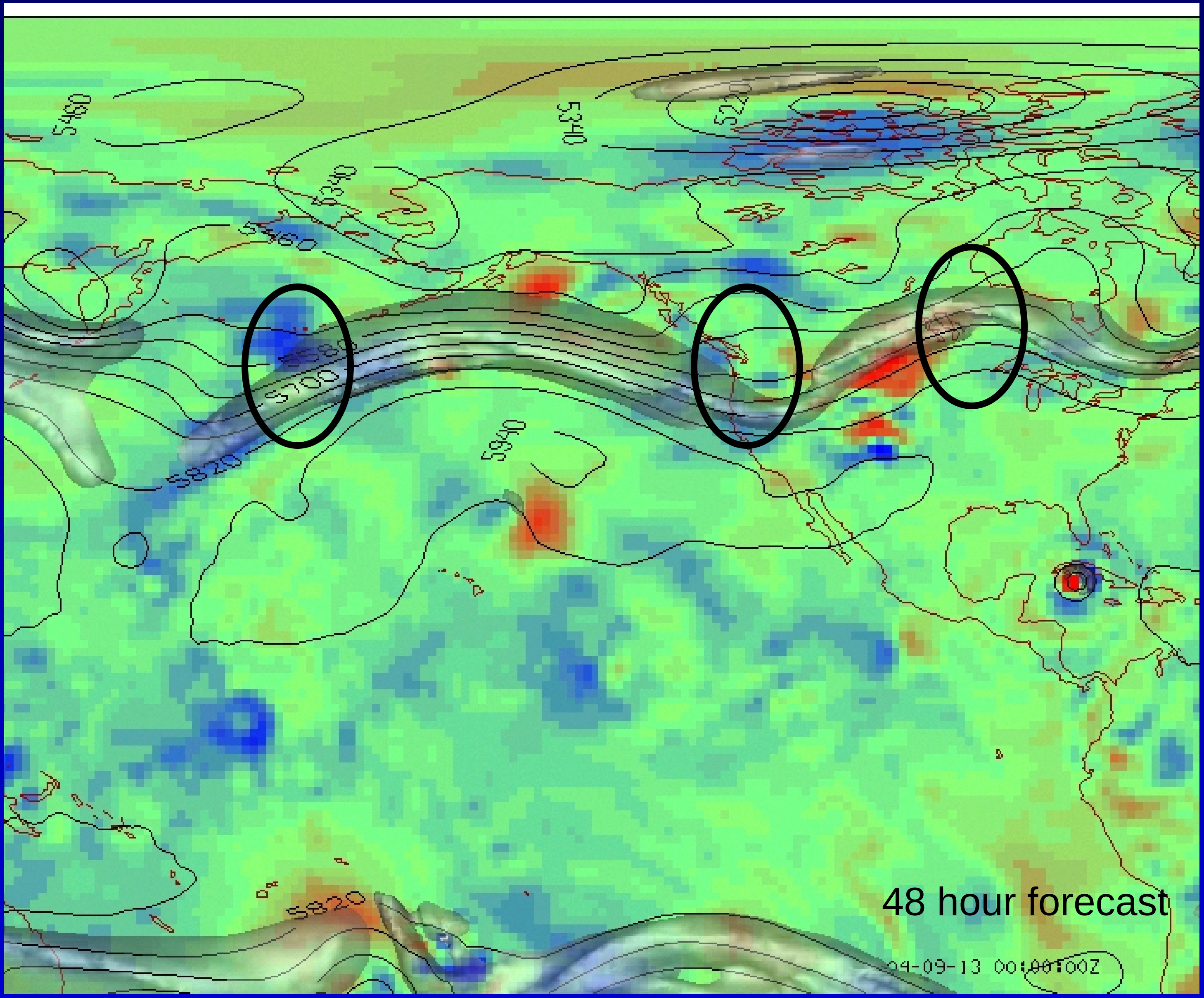
The position of the differences can be interpreted, thus:

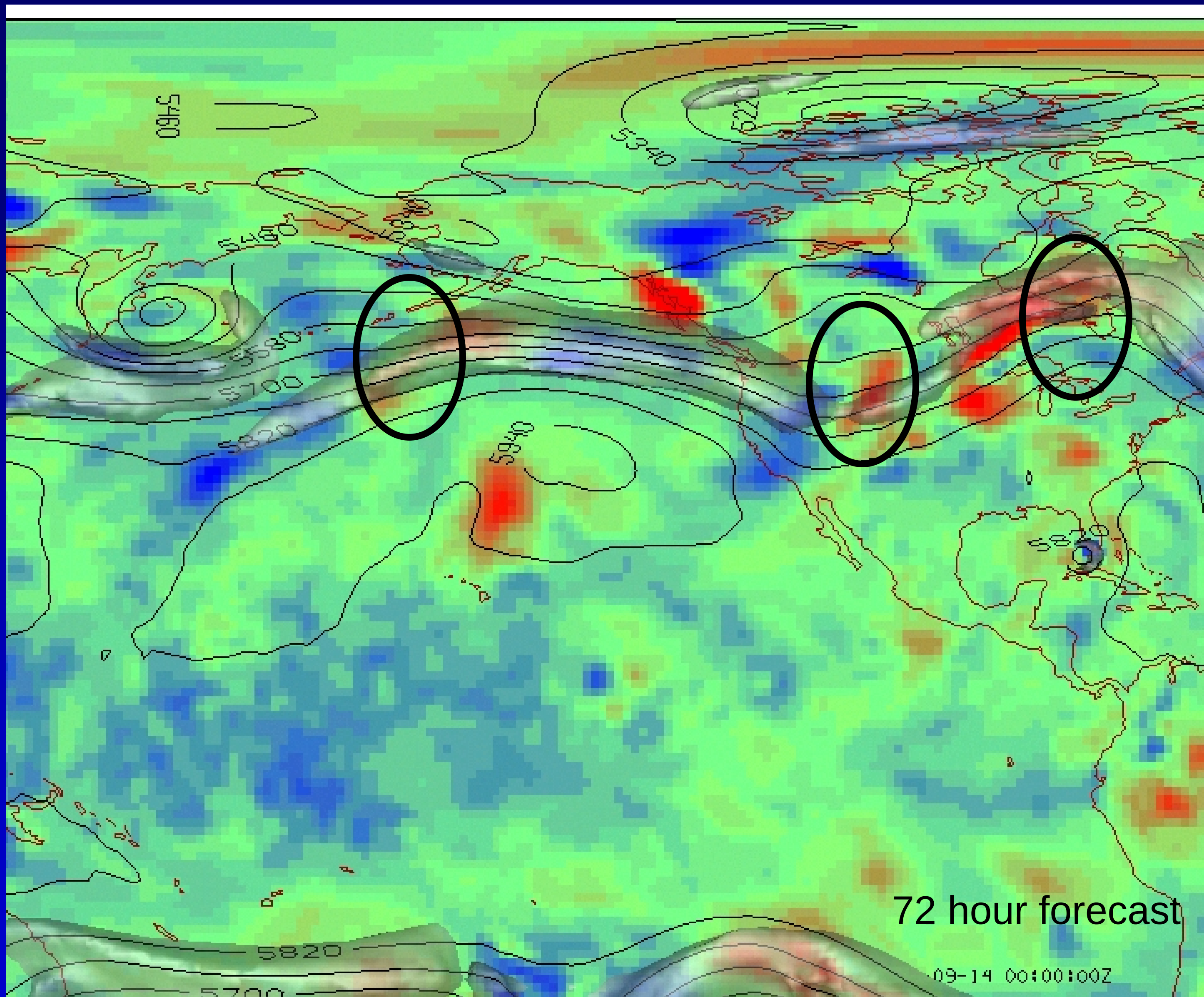
- When a difference feature is centered on a ridge or trough, it indicates a change in the amplitude of the wave.
- When the difference feature is displaced from a ridge or trough, it indicates a phase shift.

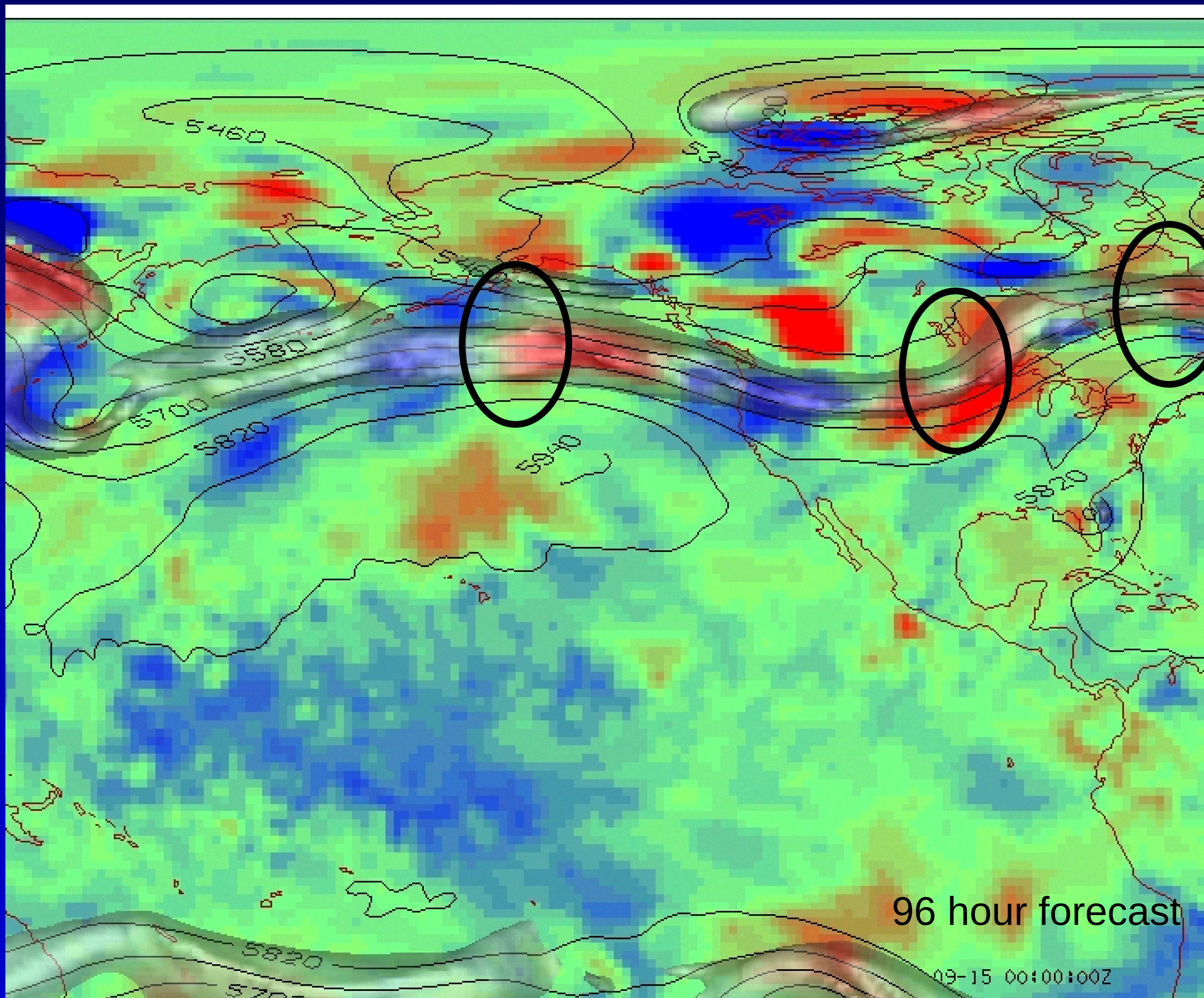
The circles are the same as the previous slides, showing where the largest difference in the divergence of the ageostrophic wind is in the analysis. Positions of circles in the forecasts represent a subjective positioning based on wave propagation.

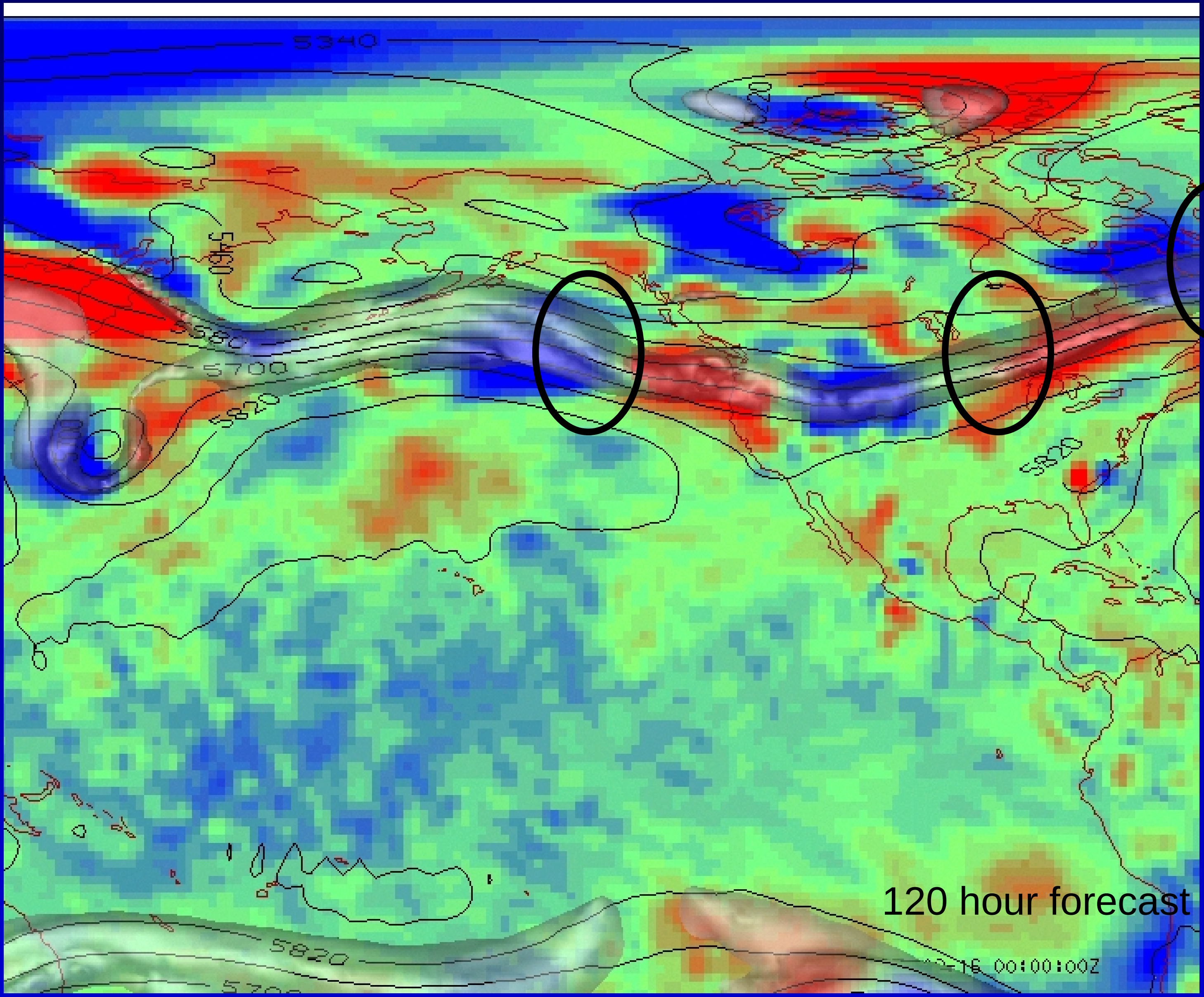

5340
5220
5460
5580
5700
5820
5820
5820
Analysis
2004-09-11 00:00:00Z


5460
5340
5700
5820
24 hour forecast

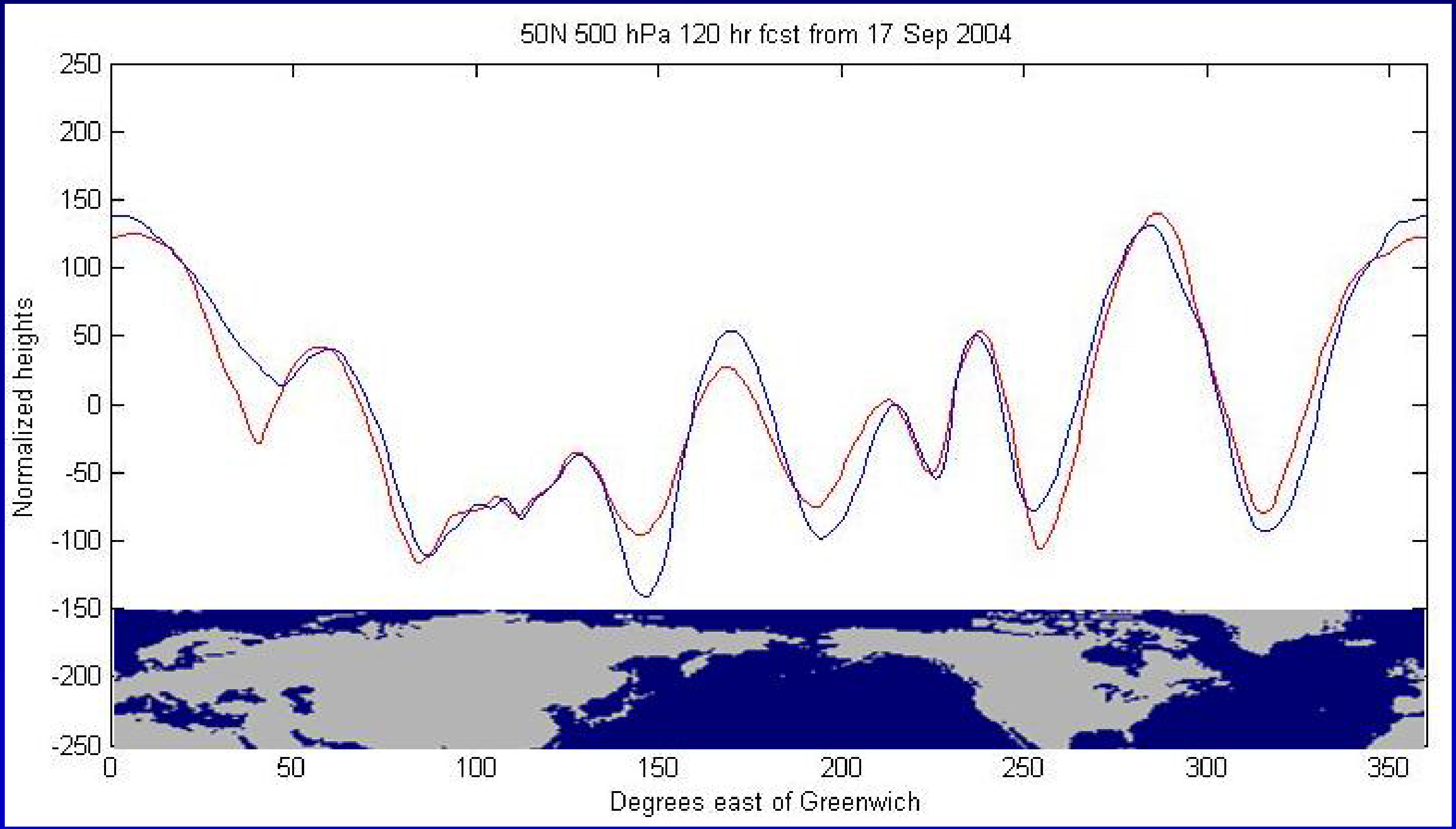

5460
5340
5220
5580
5700
5820
5940
48 hour forecast
04-09-13 00:00:00Z


5460
5220
5340
5460
5580
5700
5820
5940
5820
5820
5700
09-14 00:00:00Z
72 hour forecast


5460
5340
5580
5700
5820
5940
96 hour forecast
09-15 00:00:00Z

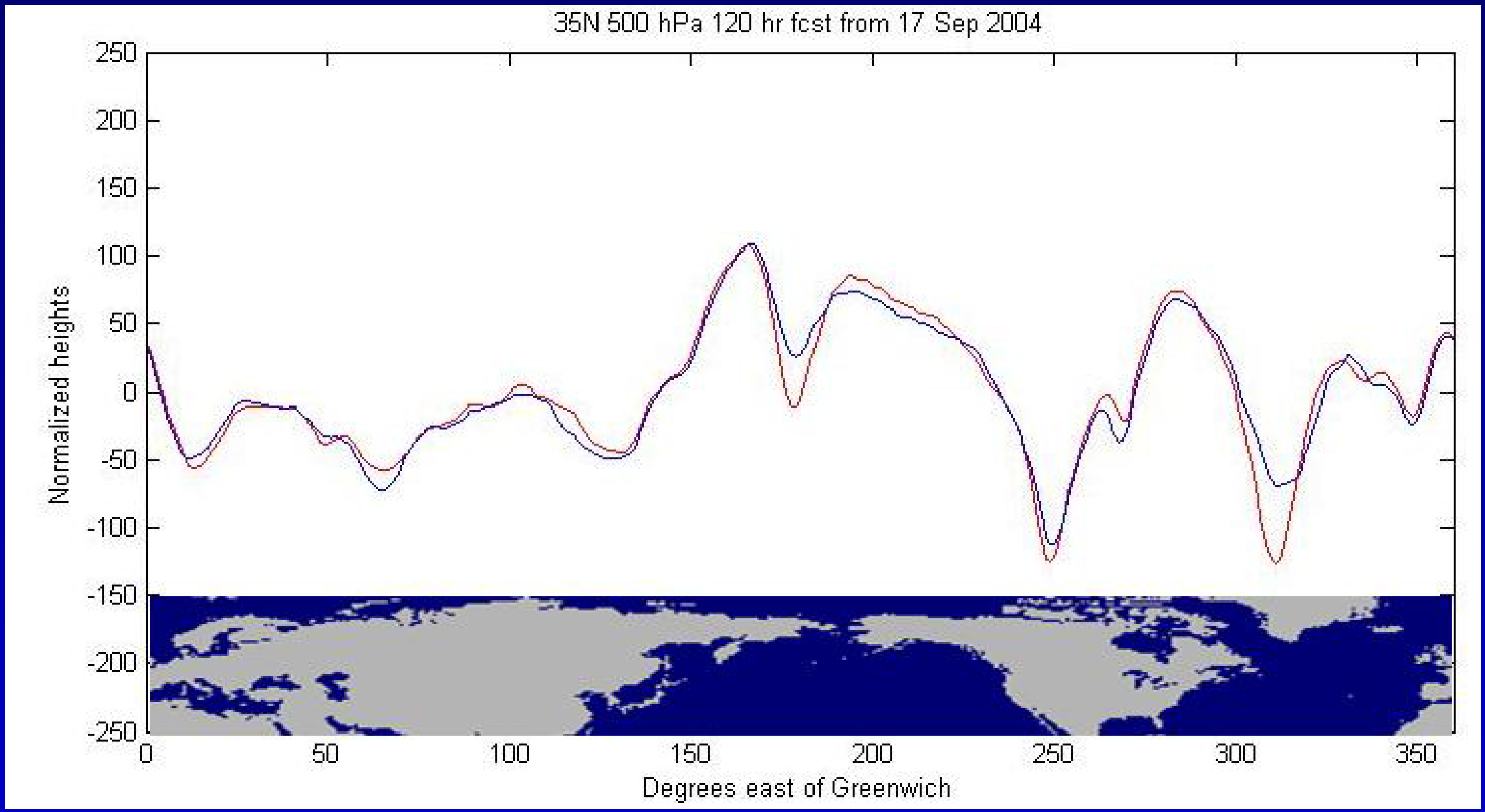

5340
5460
5580
5700
5820
5820
5820
5700
120 hour forecast

Wave Propagation Speed



Latitude slice at 50°N of 500 hPa heights for the 120 hour forecast from 17 September 2004 for the control (blue) and the MODIS winds (red).

Wave Propagation Speed



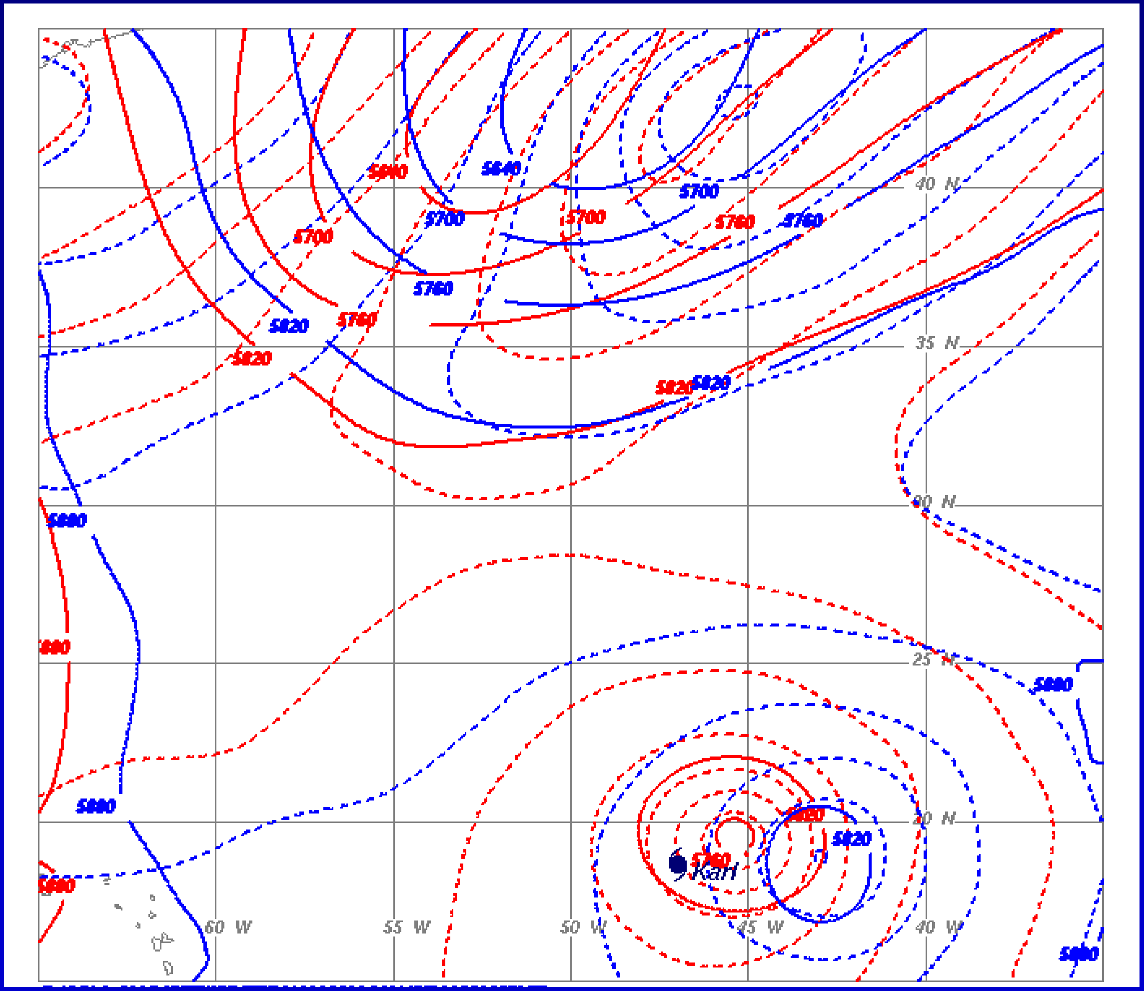
Latitude slice at 35°N of 500 hPa heights for the 120 hour forecast from 17 September 2004 for the control (blue) and the MODIS winds (red).

Forecast impact: Tropical cyclone positions

Hurricane Karl actual position and the 96-hour forecasts from the control (blue) and including MODIS winds (red).

Solid lines:
500 hPa heights.

Dashed lines:
1000 hPa heights.

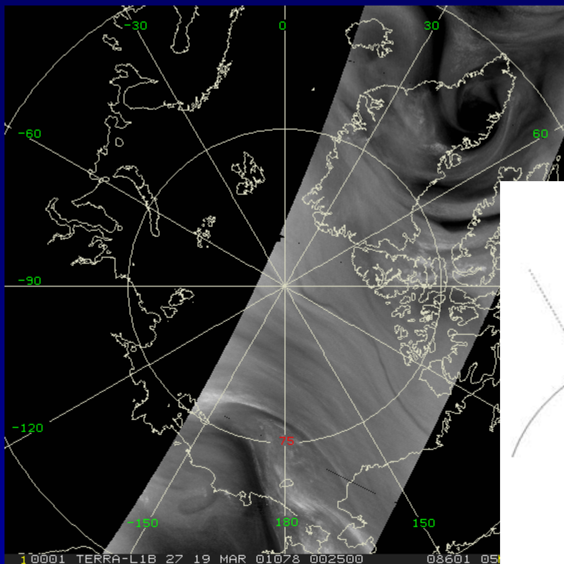


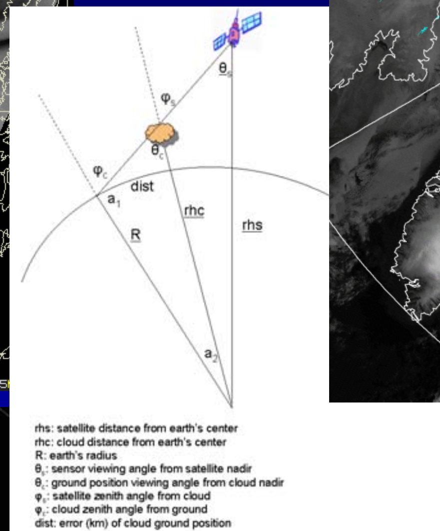
Summary

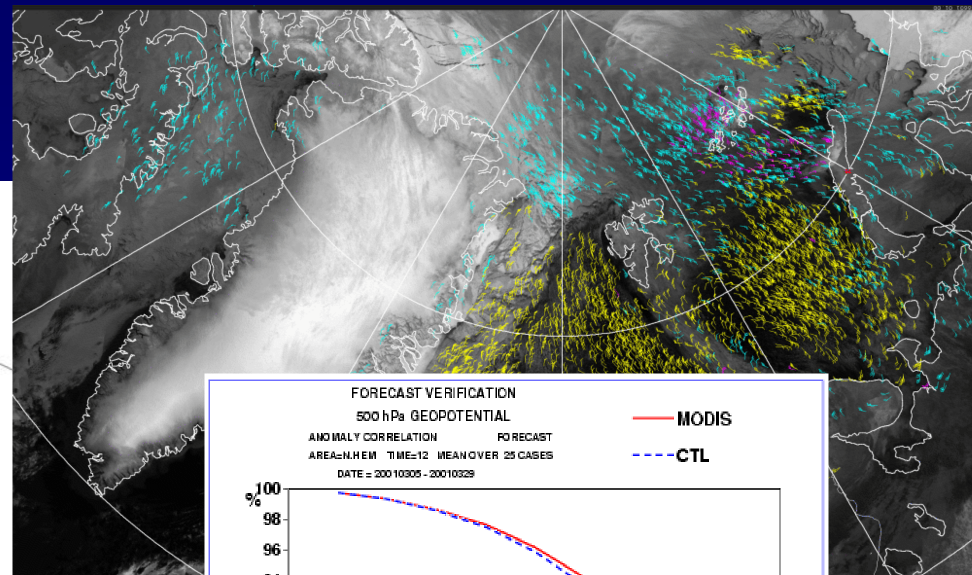
This example shows that the addition of polar winds may affect the dynamics of the waves near the jet stream, resulting in slowing the overall wave propagation.

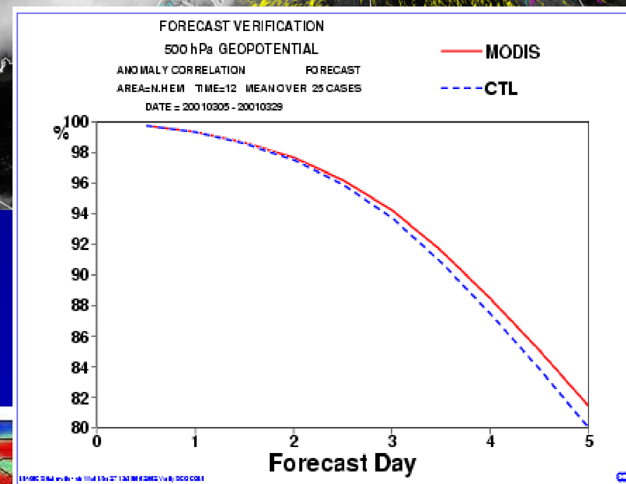
This may be the first case of assimilating high resolution data that is *only available in the polar regions*. It highlights the importance of polar observations for improving global forecasts.

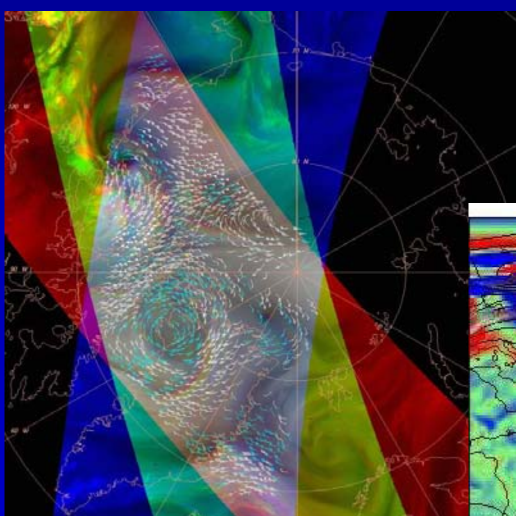
The geographic extent of the impact may be dependent on the assimilation system.

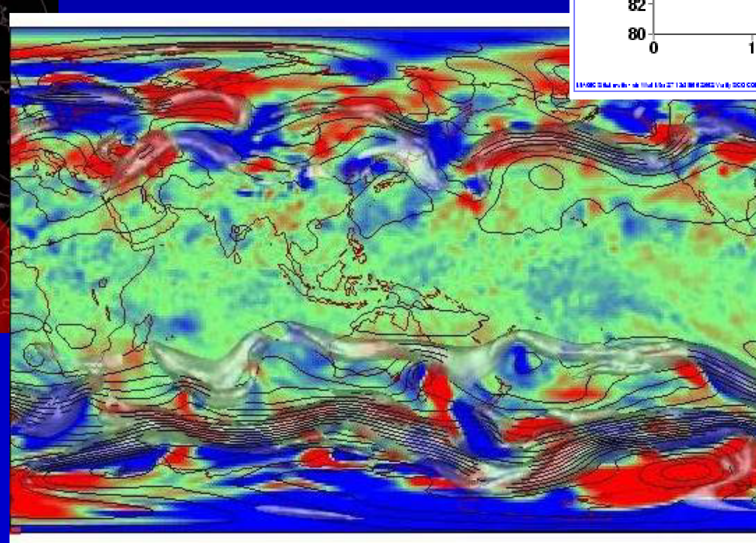


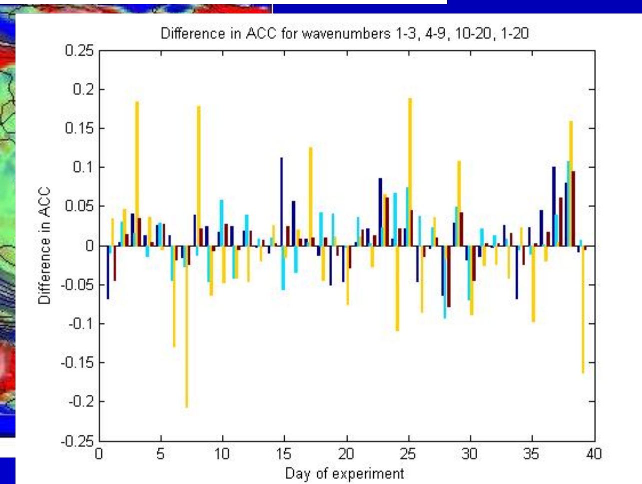








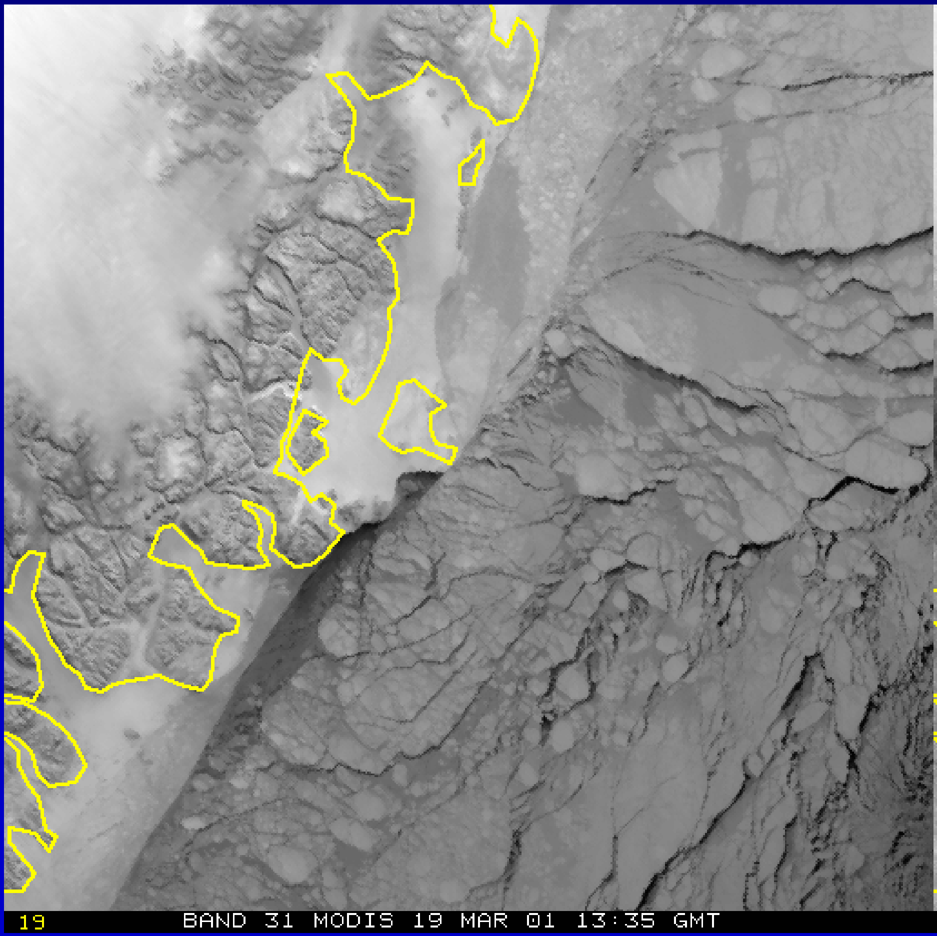




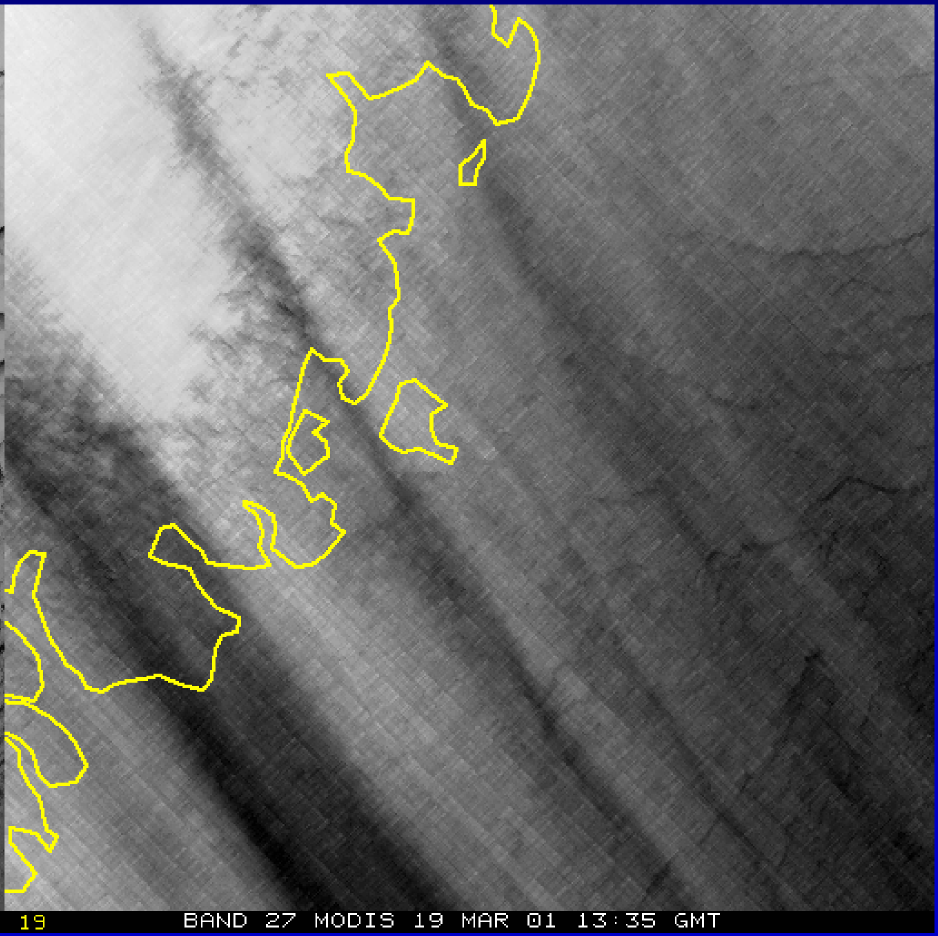
$$\nabla \bullet \vec{V}_a = -\frac{1}{f_0}\vec{V}_g \bullet \nabla \zeta_g$$

How Dry is it?

This is a MODIS image covering part of the Arctic (SE Greenland) on 19 March 2001. Surface features are clearly seen in the IR window band (left), but are also apparent in the water vapor band (right).

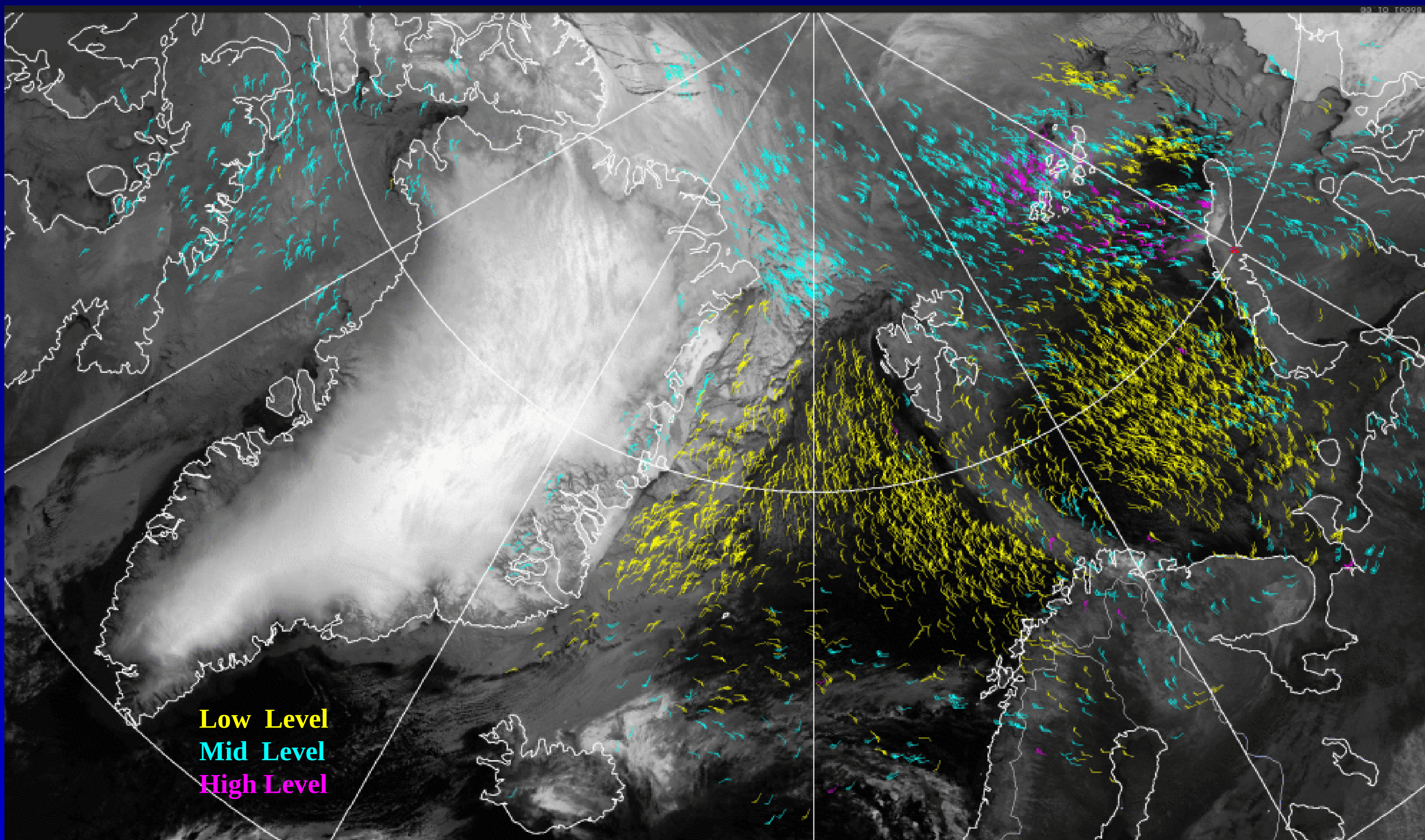


11 µm



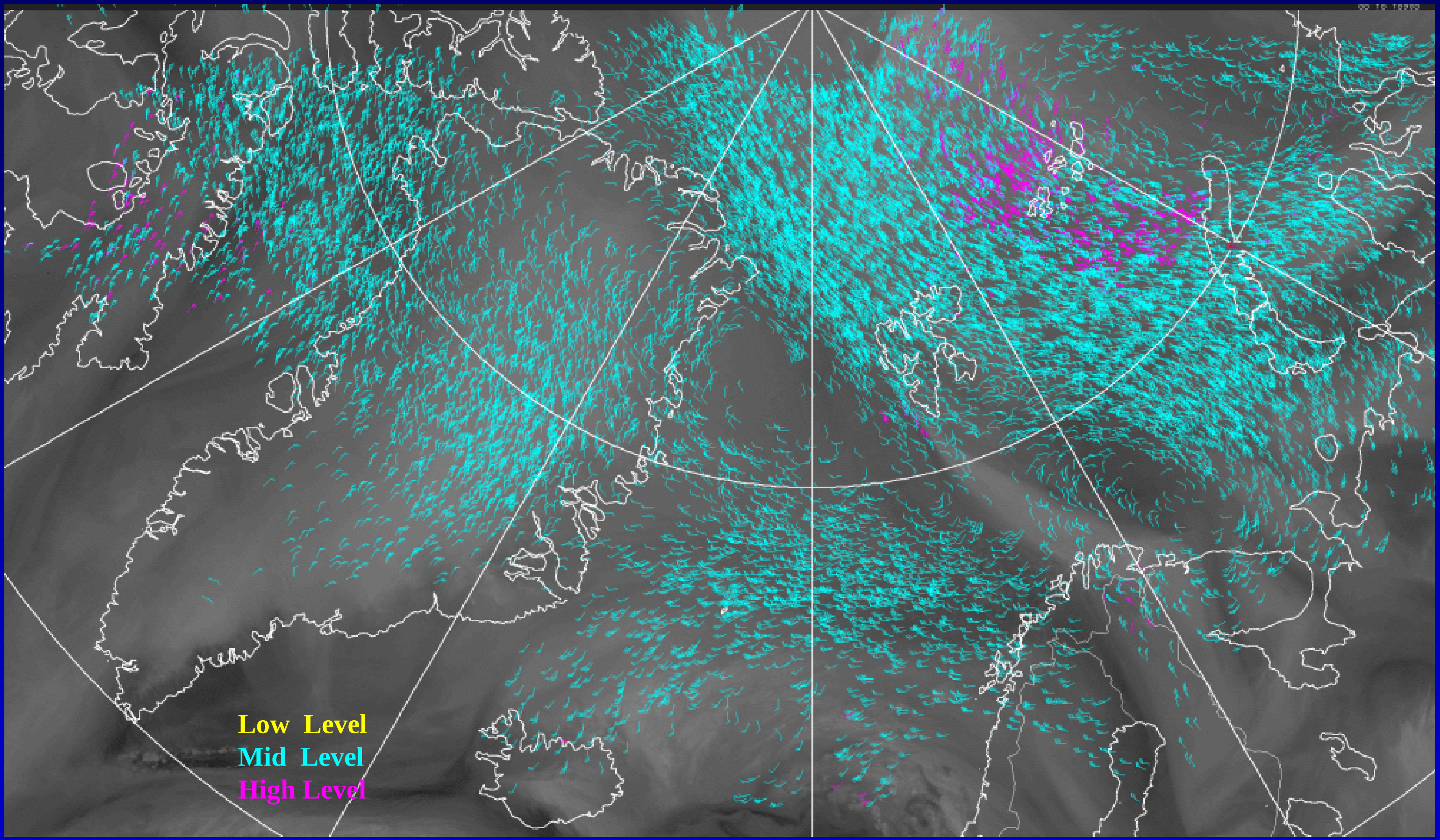
6.7 µm

Infrared Winds



05 March 2001: Daily composite of 11 micron MODIS data over half of the Arctic region. Winds were derived over a period of 12 hours. There are about 4,500 vectors in the image. Vector colors indicate pressure level - yellow: below 700 hPa, cyan: 400-700 hPa, purple: above 400 hPa.

Water Vapor Winds

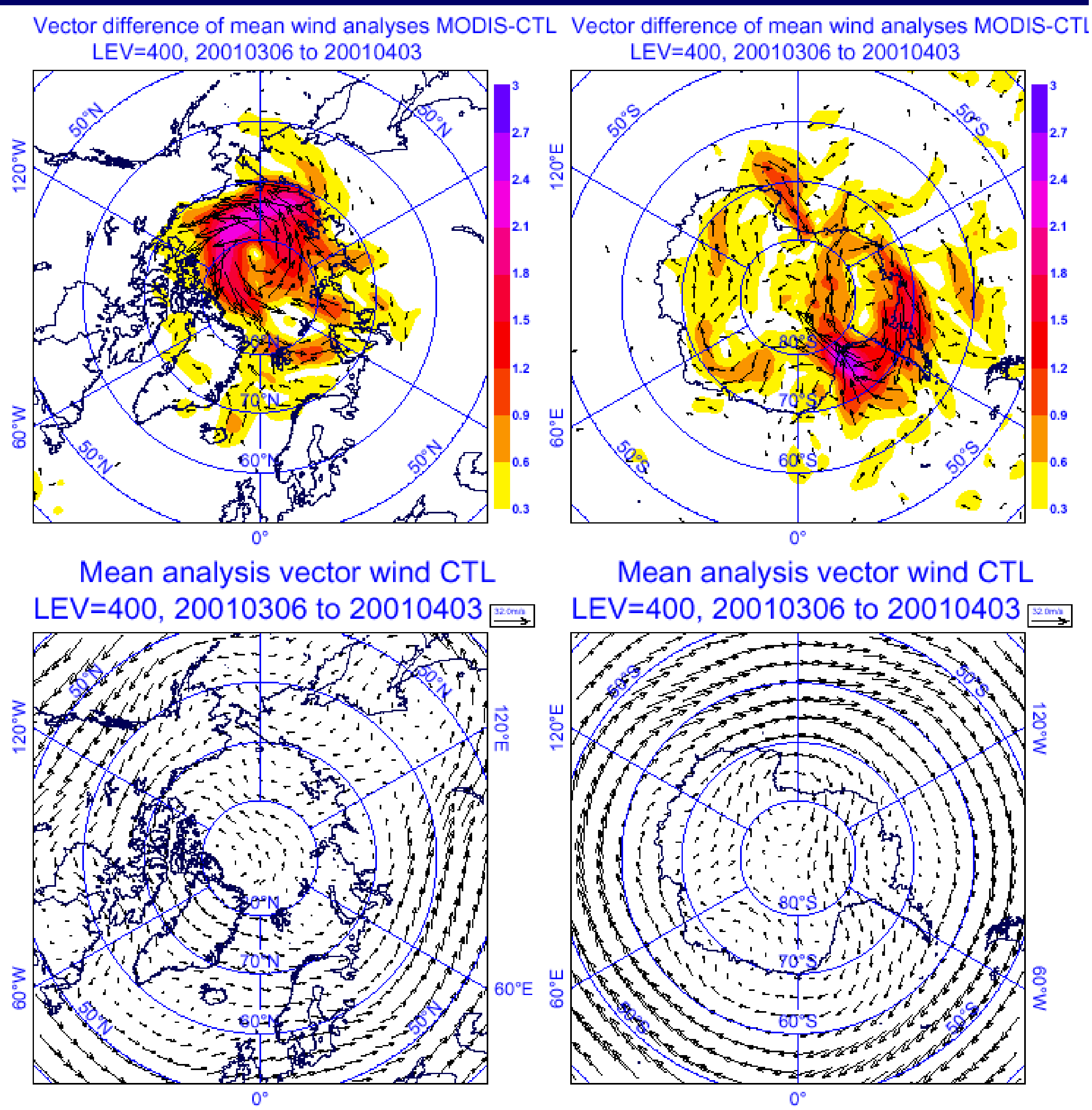


05 March 2001: Daily composite of 6.7 micron MODIS data over half of the Arctic region. Winds were derived over a period of 12 hours. There are about 13,000 vectors in the image. Vector colors indicate pressure level - yellow: below 700 hPa, cyan: 400-700 hPa, purple: above 400 hPa.

ECMWF Mean and Difference Wind Fields: 400 hPa

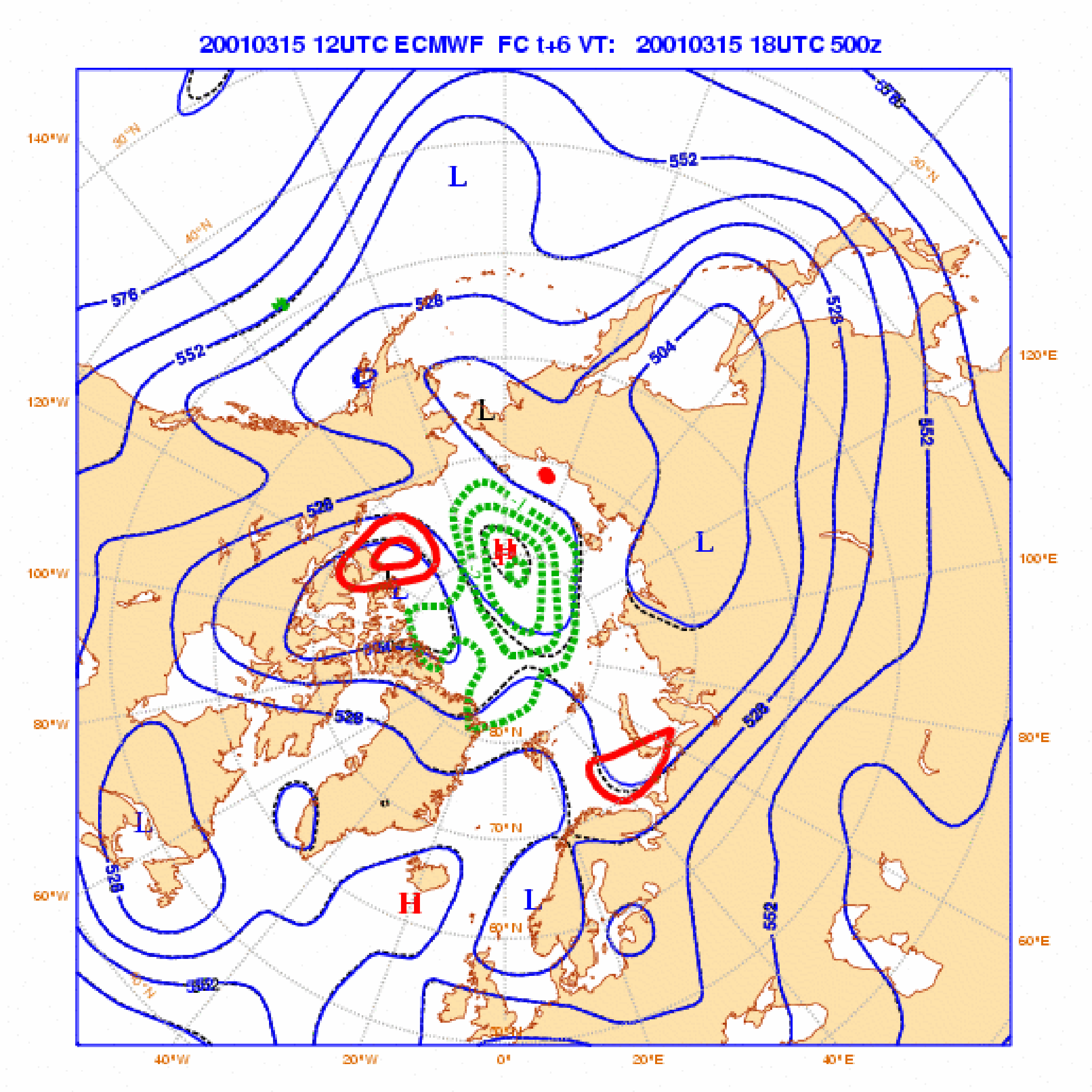
Arctic: MODIS winds act to strengthen the circulation at upper levels.

Antarctic: MODIS winds act to strengthen the flow around the Antarctic Peninsula.



ECMWF: Propagation to the Midlatitudes

Each frame shows the 500 hPa geopotential height for forecasts from 1 to 5 days in 1 day increments. The solid blue line is the geopotential that included MODIS winds; the dashed black line is the control (CTL) without MODIS winds. Solid red lines show positive differences in the geopotential height (MODIS minus CTL), and thick dashed green lines show negative differences.



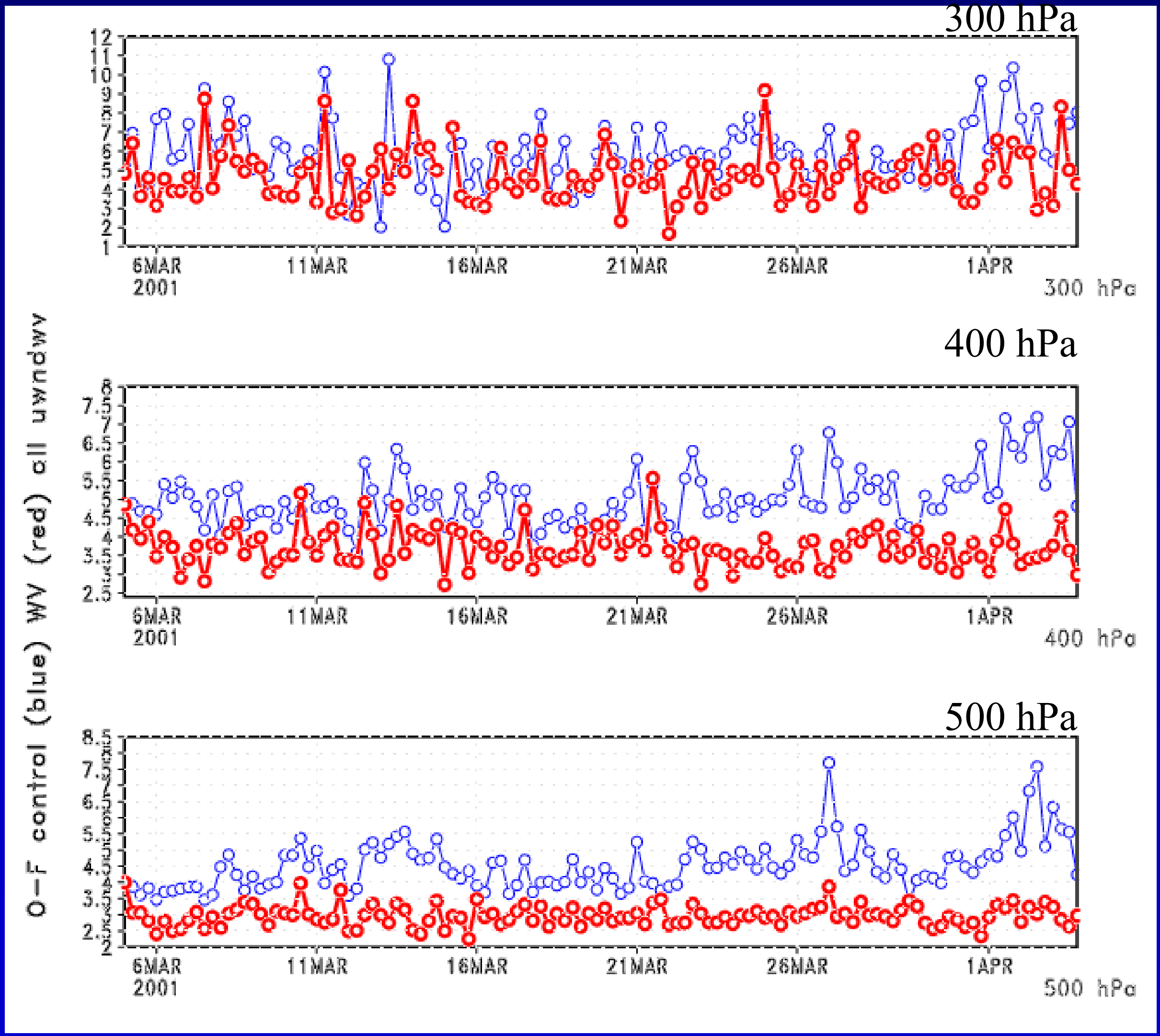
Better observations over the poles should improve forecasts in the midlatitudes.

Model Impact Studies: GMAO

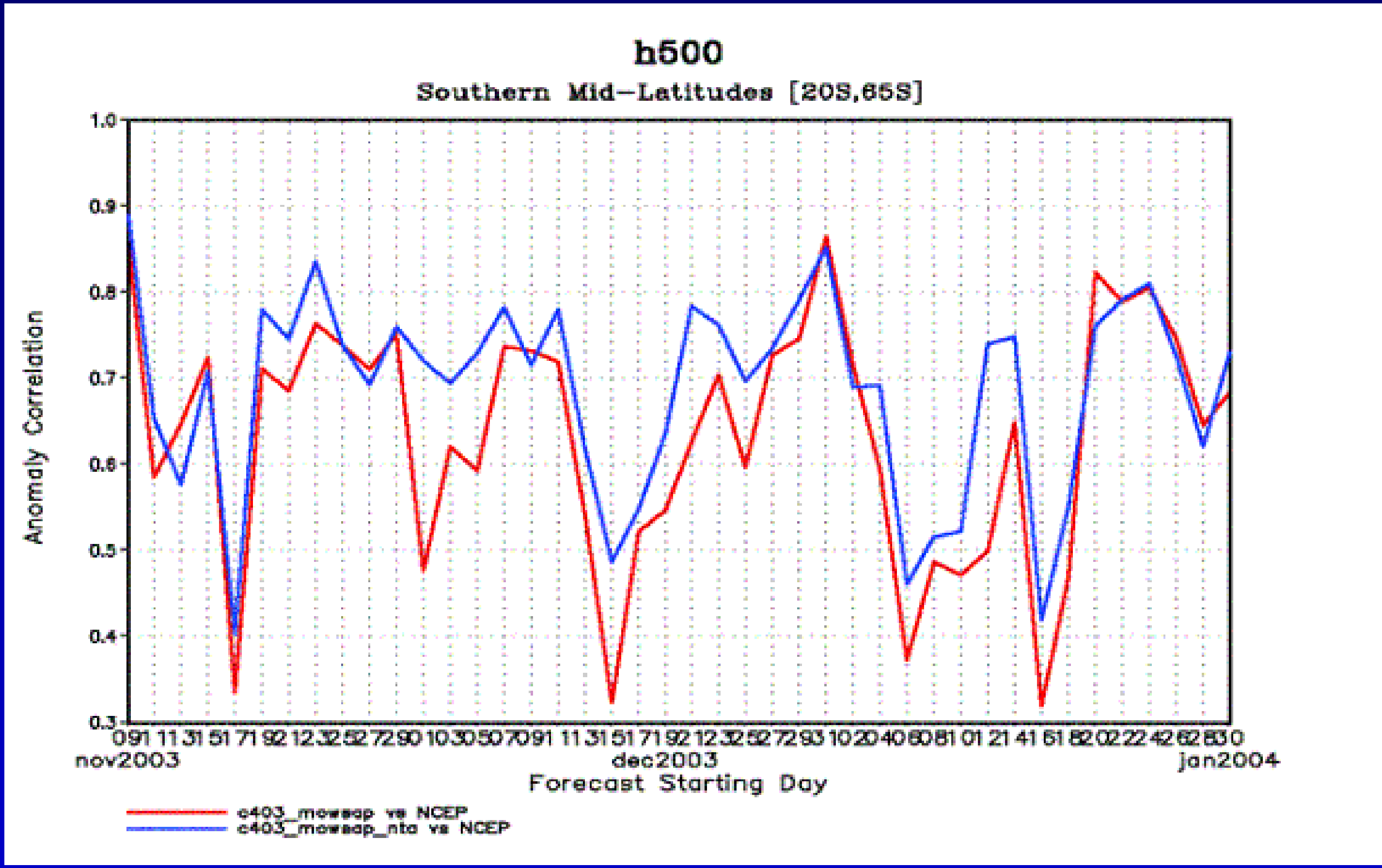
RMS wind speed differences between the MODIS water vapor winds and the 6-hr model forecast with (red) and without (blue) the MODIS winds for a 30 day period. Results are shown for three levels: 300, 400, and 500 hPa. This is a validation of the model against the MODIS winds.

Lars Peter Riishojgaard (NASA GMAO) said: "….the 500 hPa water vapor winds seem to reduce the short-range forecast errors for the winds by about 40%."

RMS observation minus forecast residual



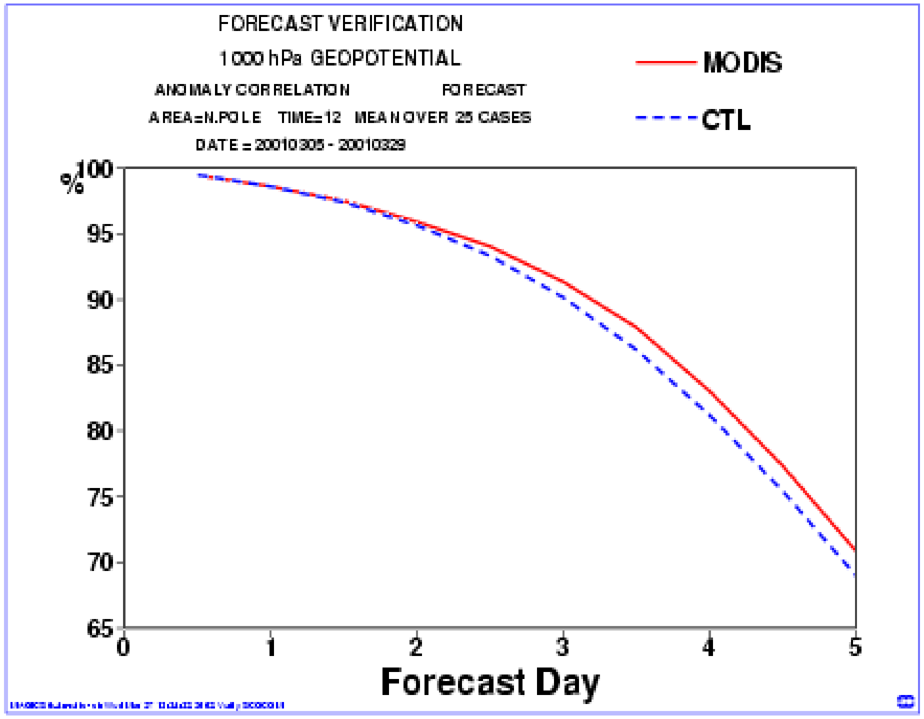
Model Impact: GMAO



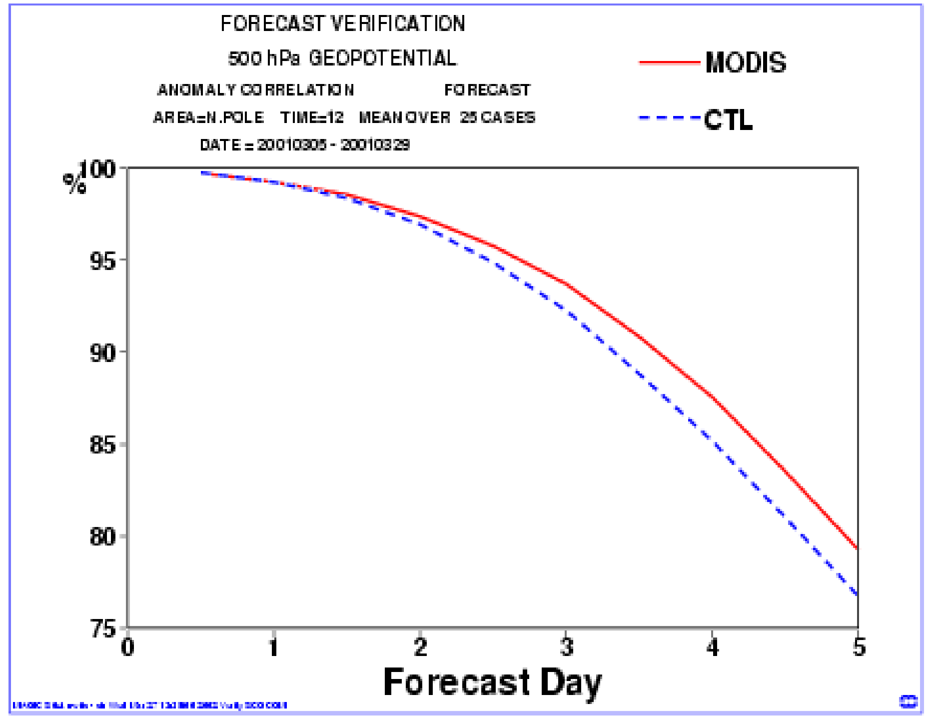
500 hPa anomaly correlation for the southern hemisphere mid-latitudes from Nov. 2003 through Jan. 2004. The red represents the control; the blue includes MODIS polar winds. From the NASA GMAO.

ECMWF Model Impact: Arctic

1000 hPa



500 hPa



Anomaly Correlation Coefficient as a function of forecast day for the geopotential at 1000 hPa (left) and 500 hPa (right). Study period is 5-29 March 2001. The correlation is between the forecast geopotential height anomalies, with and without the MODIS winds, and their own analyses. The Arctic is defined as north of 65 degrees latitude.

There is a significant positive impact on forecasts of the geopotential from the assimilation of MODIS winds, particularly for the Arctic.

Dynamic Bias Correction

A bias correction is a statistical technique to account for systematic errors in the observations, which is important since the assimilation system assumes only random errors are present. A dynamic bias correction for satellite radiances is built into the GDAS, which is unlike other observations (such as, rawinsondes) where the bias correction is applied outside the assimilation. This correction accounts for the combined biases in the radiative forward model, instrument, number of vertical levels, airmass, etc. which can not be determined independently.

Spectral Assimilation

- All the data are interpolated globally. The weighting is less for observations farther from the grid point, but it is evident in poorly observed regions.
- The analyses are initialized as an independent step resulting in adjustments away from the data. This initialization is necessary to correct for any imbalance in the mass and temperature fields that could result in amplifying gravity waves.

Gravity Waves

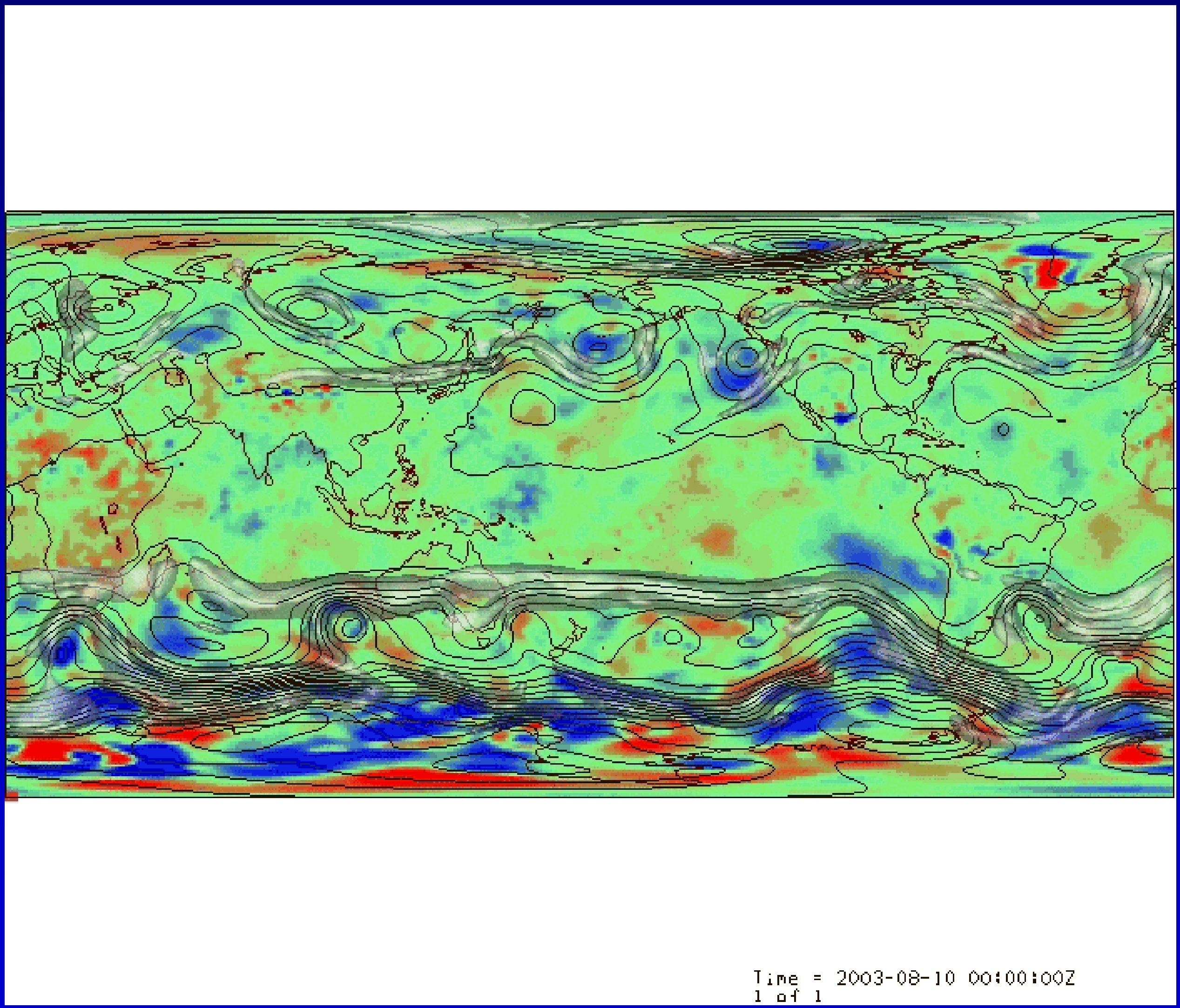
Gravity waves may affect the entire circulation in just a few time steps, in as little time as a few minutes. Grid point models may change the fields farther away faster through gravity waves than spectral models. Even though spectral models truncate to a certain maximum wave number every time step, changes to all fields will still occur rather quickly and spread throughout the entire domain.

Global AMSU Radiance Assimilation

Same as previous slide, except the AMSU data was inadvertently added back into the run that was being denied. This was done on 24 Aug 2003.

After the first 24 hours, the magnitude of the differences drops off significantly, but difference patterns are still evident.

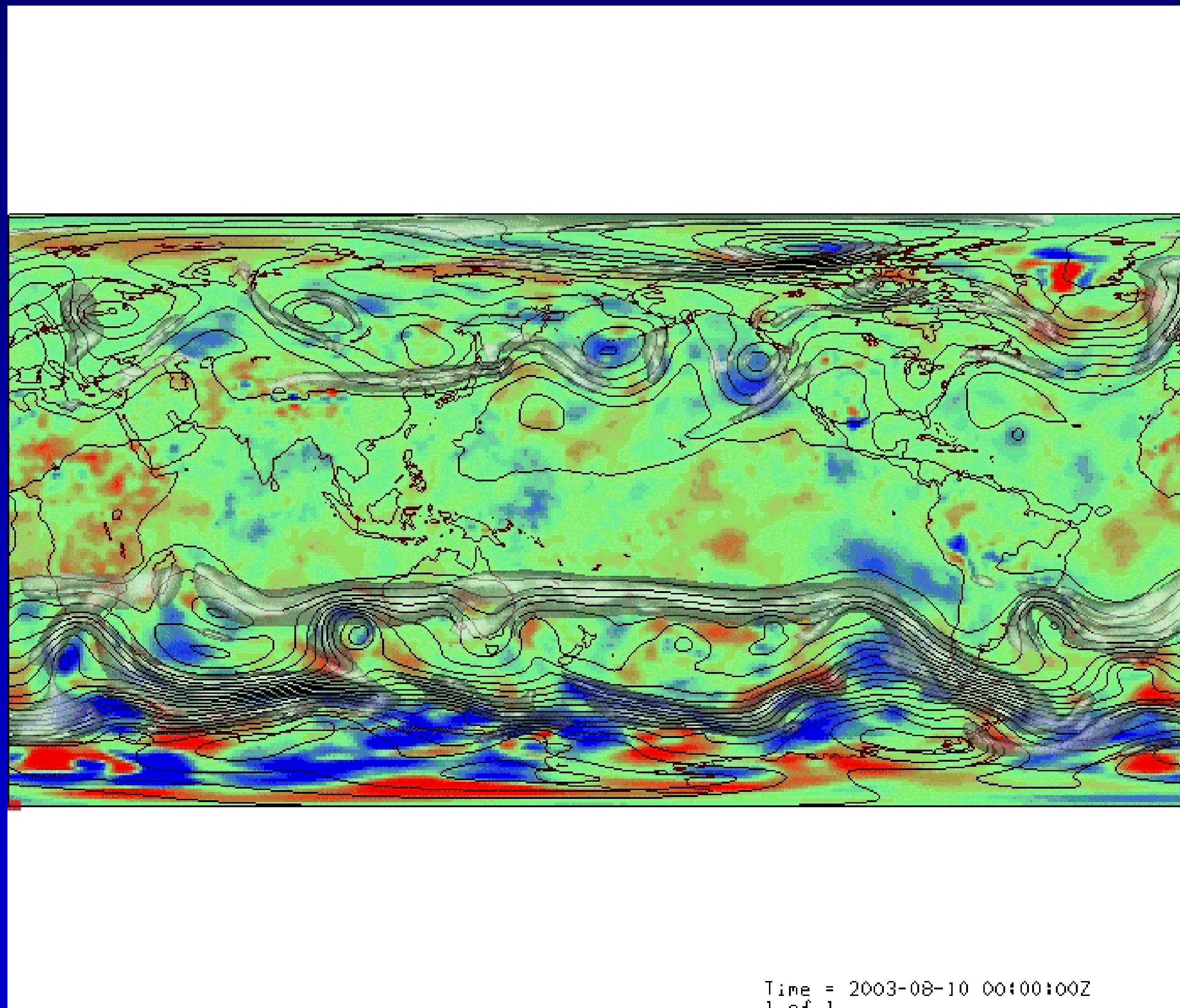
Even after 8 days with both runs including the same data, there are still differences, especially in the tropical convective regions. But, there are differences in other areas, where other data exists.



Global AMSU Radiance Assimilation

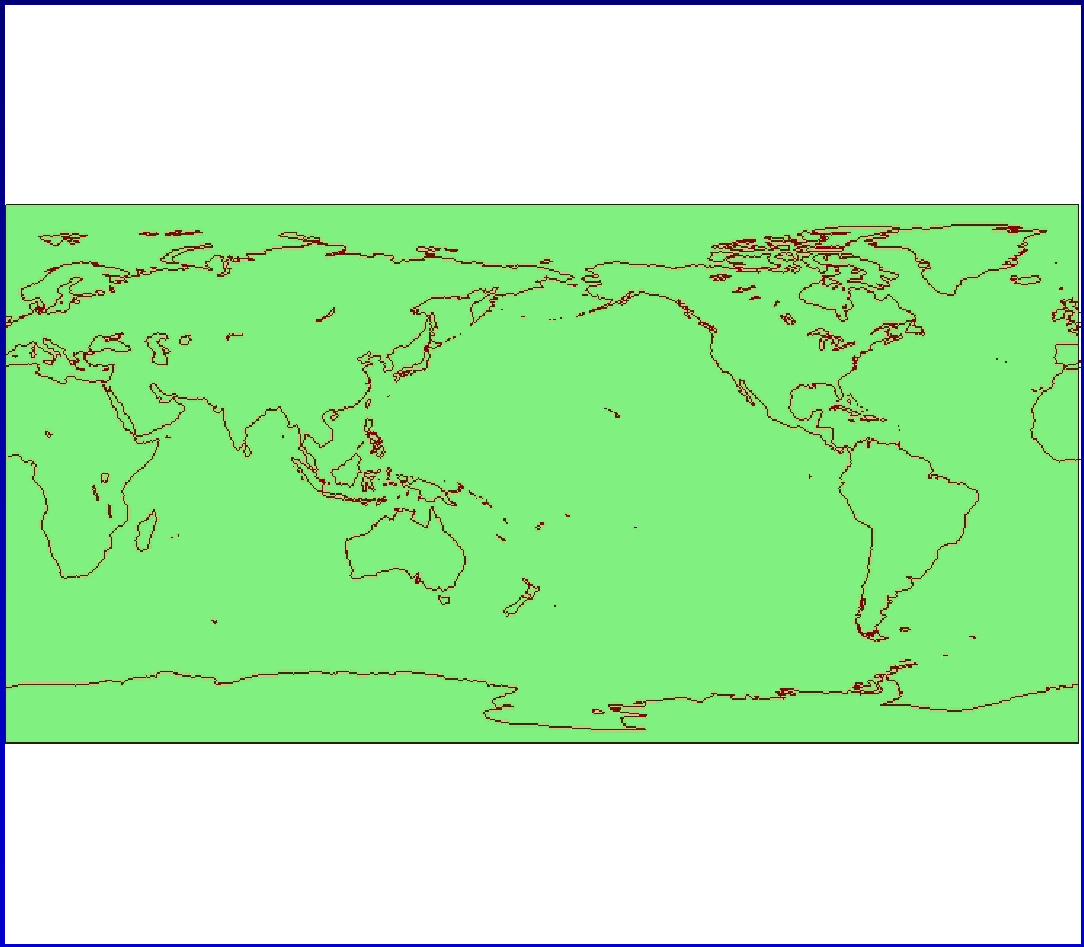
1000-500 hPa thickness difference between control and no AMSU radiances analyses. The range from blue to red is from -30 to +30 gpm difference. Near zero difference in green. 30 m/s wind speed in transparent white. Black contours are the 500 hPa heights.

This is a 2 week denial experiment in August 2003.

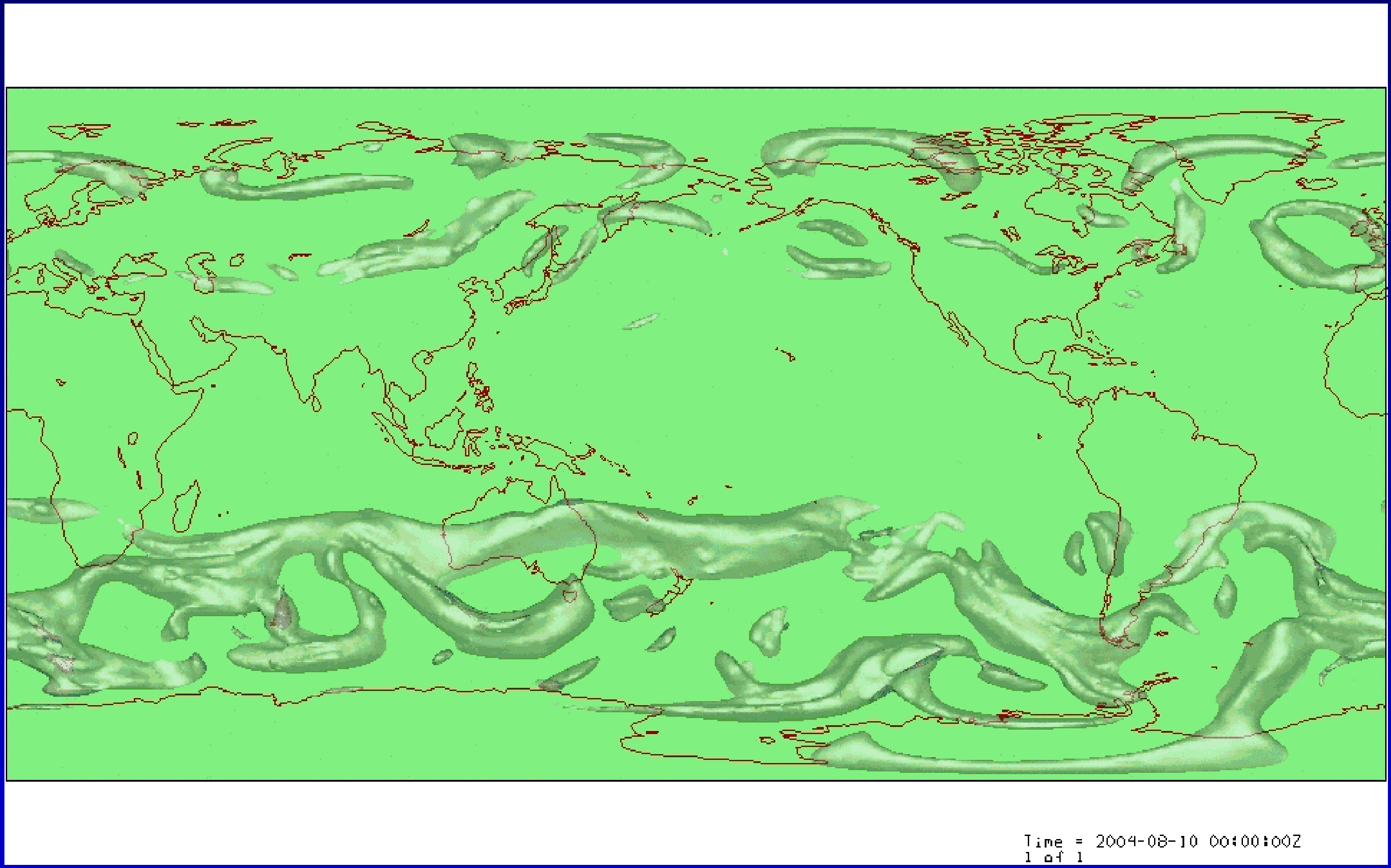


MODIS Winds in NOGAPS Model

NOGAPS analysis grids for 10 days, every 12 hours. The difference is the 1000-500 hPa thickness. The color scale is -30 [blue] to +30 [red] gpm; with green being close to zero difference. Red means the MODIS winds have increased the thickness. Begins at 00Z on 10 Aug 2005.

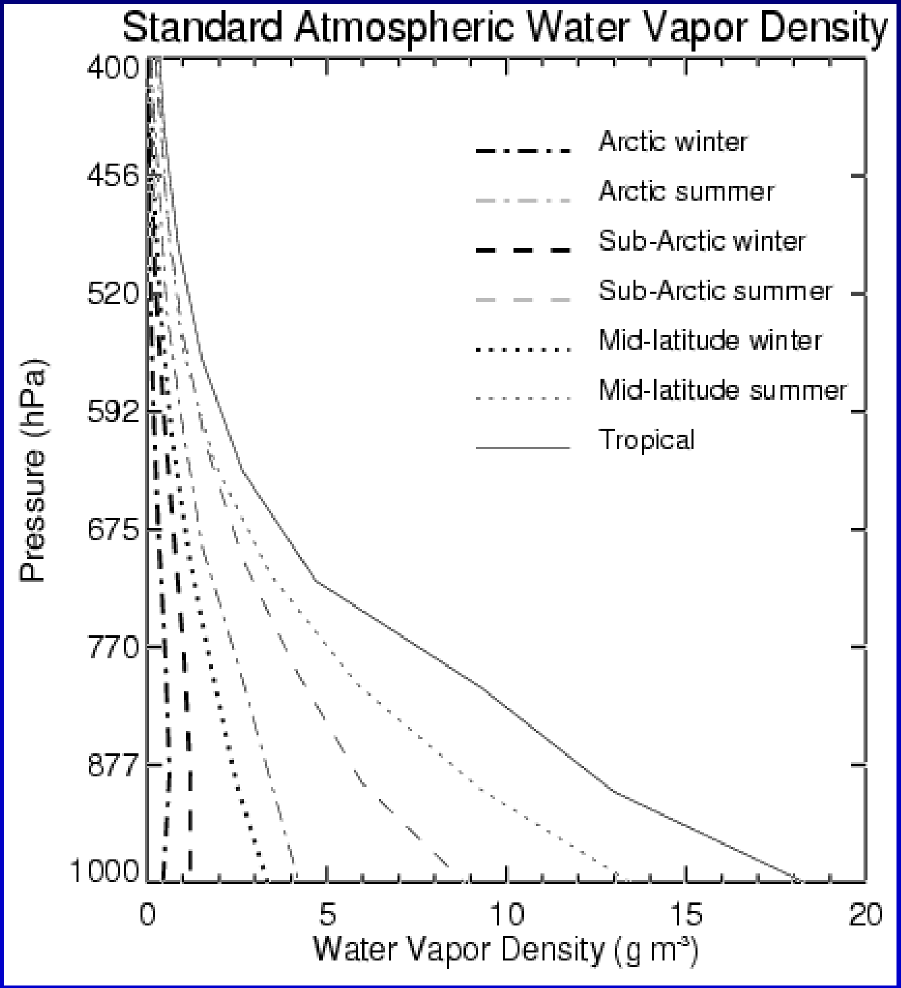


1000-500 hPa Thickness Differences

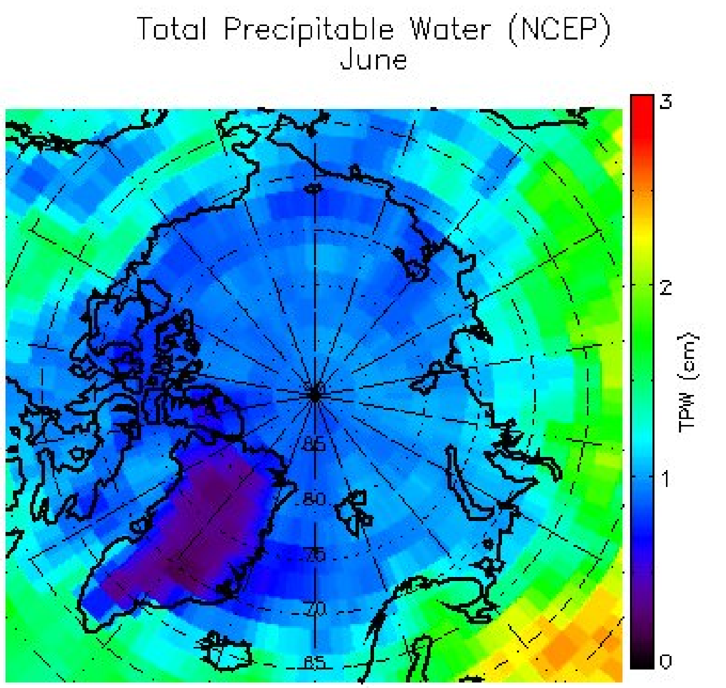


1000-500 hPa thickness difference between control and MODIS winds analyses. The range from blue to red is from -30 to +30 gpm difference. Near zero difference in green. 30 m/s wind speed in transparent white. Analyses from 10-24 Aug 2004.

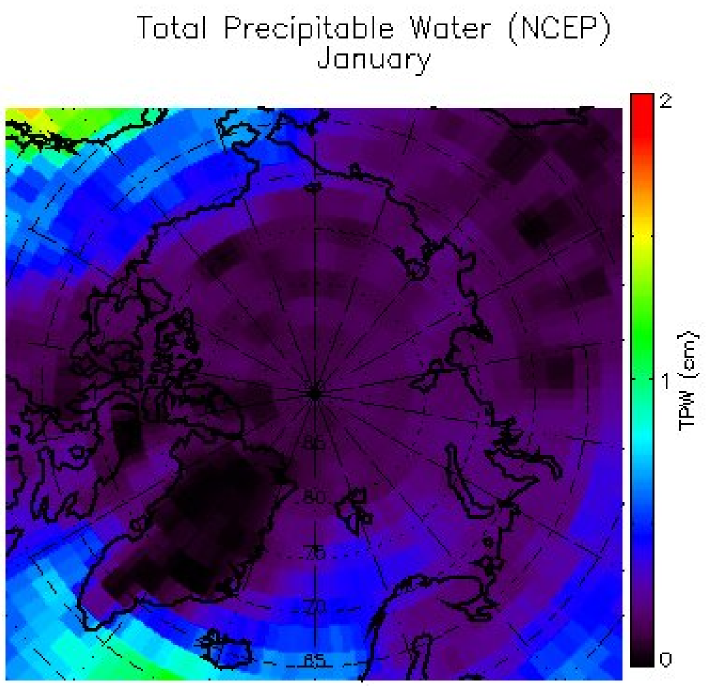
Water Vapor



Standard Atmospheric Water Vapor Density
Pressure (hPa)
400
456
520
592
675
770
877
1000
0
5
10
15
20
Water Vapor Density (g m⁻³)
Arctic winter
Arctic summer
Sub-Arctic winter
Sub-Arctic summer
Mid-latitude winter
Mid-latitude summer
Tropical



Total Precipitable Water (NCEP)
June
TPW (cm)
3
2
1
0



Total Precipitable Water (NCEP)
January
TPW (cm)
2
1
0

Restatement

Feature-tracked winds derived from a time sequence of MODIS imagery over the polar regions are routinely input into many operational global numerical models. These same centers report that the winds have a positive impact on forecasts not only in the polar regions, but also into mid- and lower-latitudes, especially in 3 to 5 day forecasts and forecast bust situations.

The MODIS winds are only derived poleward of 65 degrees latitude. What are possible explanations for this global impact?

Two areas are being investigated:

1) 3DVAR assimilation

2) Dynamics near the jet stream

Data Assimilation

When the MODIS winds are assimilated, a mass adjustment takes place. This also results in a change in the temperature structure to maintain a thermal balance. As expected, most of the mass adjustment takes place near and poleward of the jet stream.

When AMSU radiances are assimilated, the thermal structure changes, which also results in a mass adjustment. These data are global.

Geostrophic wind

$$V_g \equiv f_0^{-1} k \times \nabla_p \Phi$$

Thermal wind

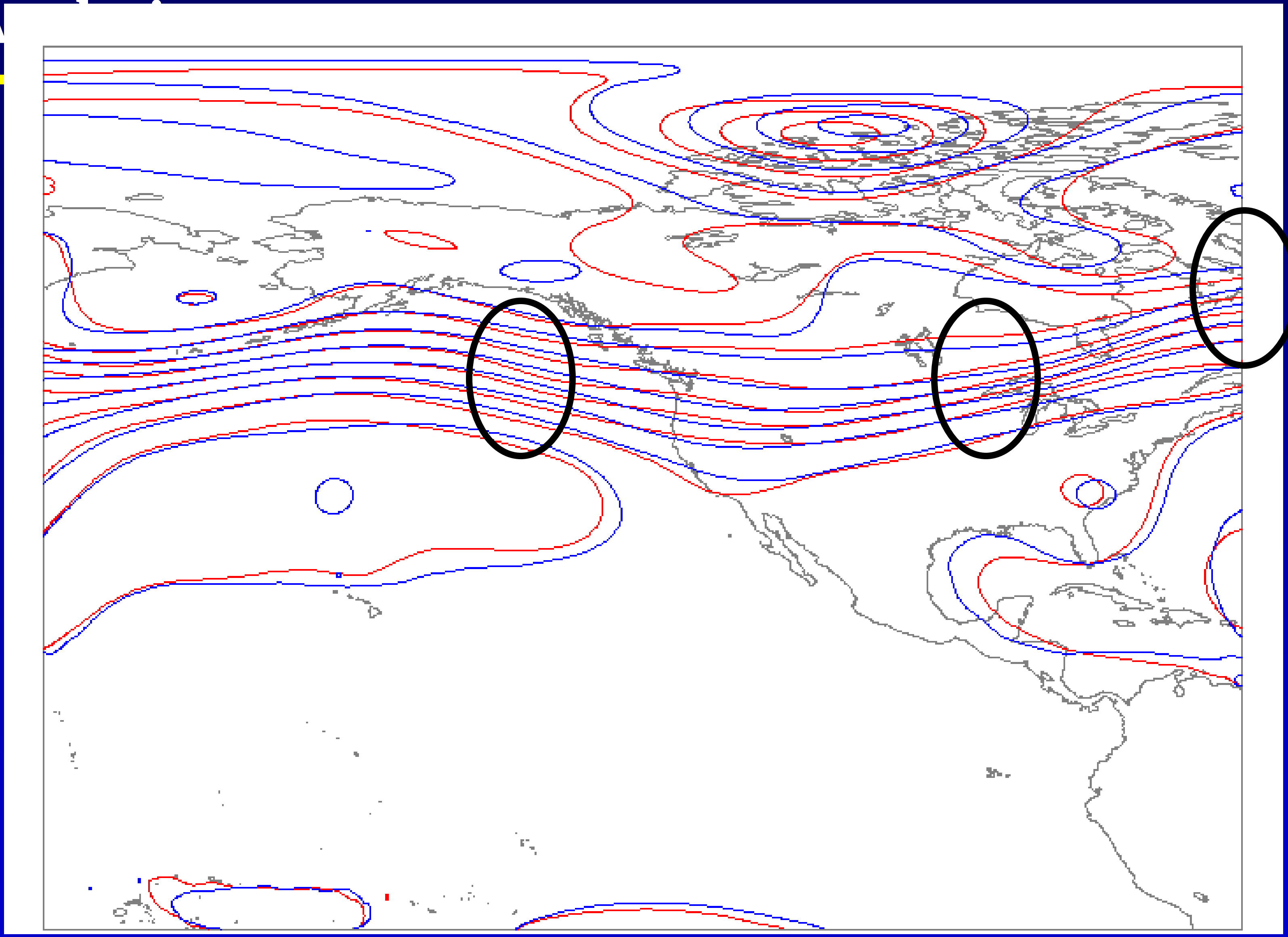
$$V_T = f_0^{-1} k \times \nabla(\Phi_1 - \Phi_0)$$

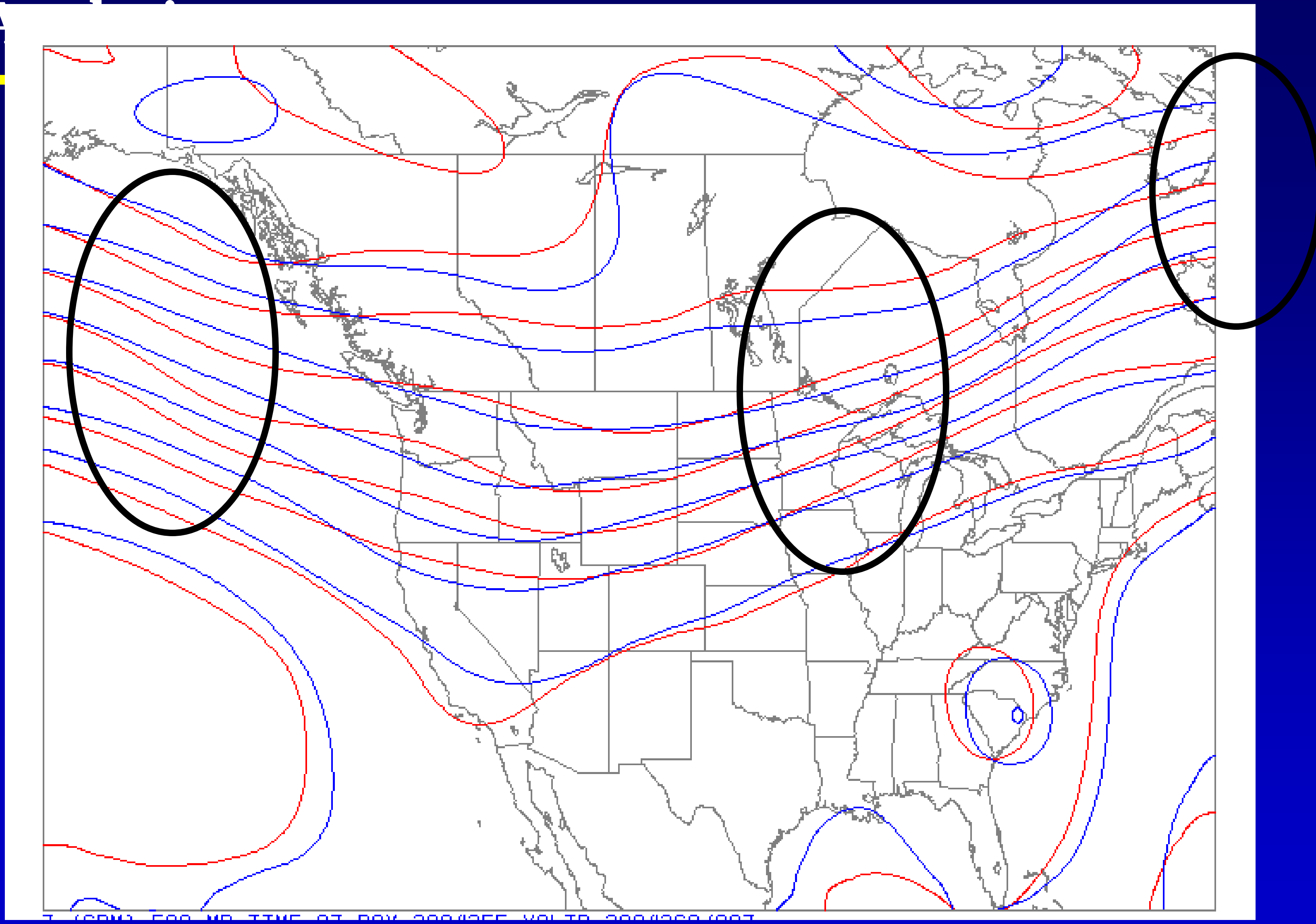
$$\Phi_1 - \Phi_0 = R\langle T \rangle \ln(p_0 / p_1)$$

Analysis

Forecast impact: Heights

- The following 2 slides are the 120 hour forecast contours of the 500 hPa heights for MODIS (red) and control (blue). The first slide is about the same geographic coverage as the previous slides. The second slide is a close-up.
- The circles are the same as the previous slides.





Analysis

Number of MODIS wind observations that are potentially available for the 0000 GMT cycle for the five case studies.

Day	Number of Winds
06 Sep 2004	21,300
07 Sep 2004	12,271
11 Sep 2004	15,075
12 Sep 2004	7,115
17 Sep 2004	15,303

Impact in Tropics: GFS Model

Impact of MODIS winds on
hurricane track forecasts from the JCSDA

Average hurricane track errors (nm)

13.2	66.5	102.8	301.1	Cntrl
11.4	60.4	89.0	252.0	Cntrl + MODIS
74	64	52	34	Cases (#)
00-h	24-h	48-h	120-h	Time

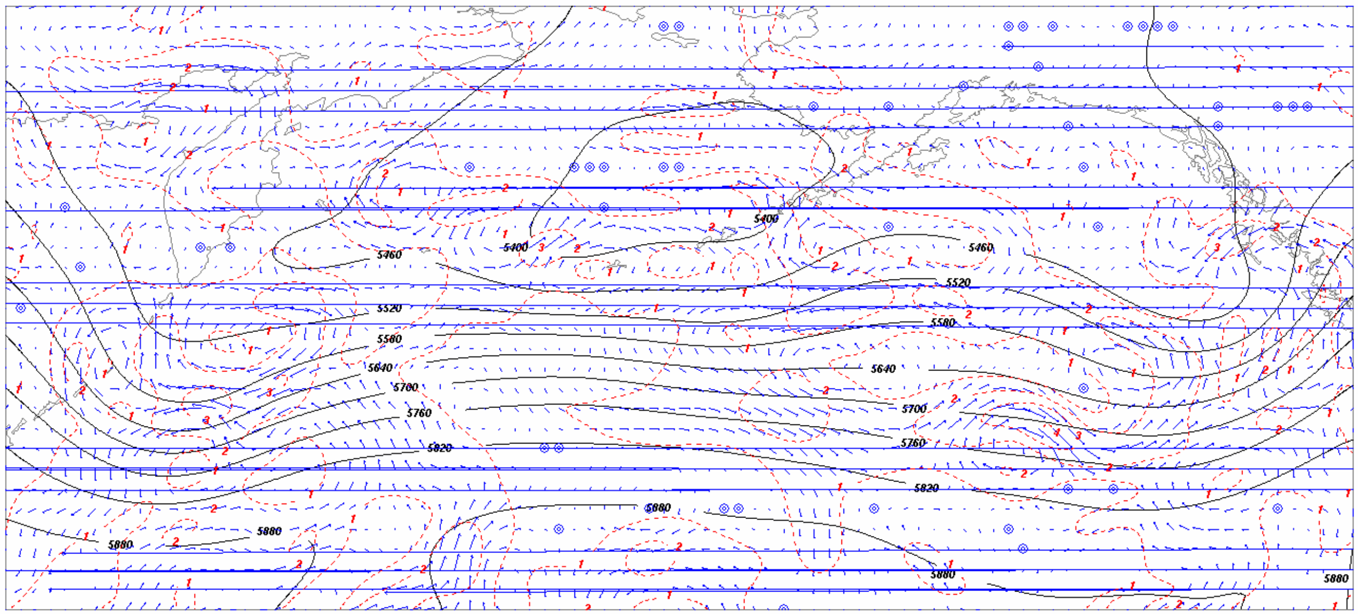
Frequency of superior hurricane performance

48.9	44.8	39.6	29.4	Cntrl
51.1	55.2	60.4	70.6	Cntrl + MODIS
74	64	52	34	Cases (#)
00-h	24-h	48-h	120-h	Time

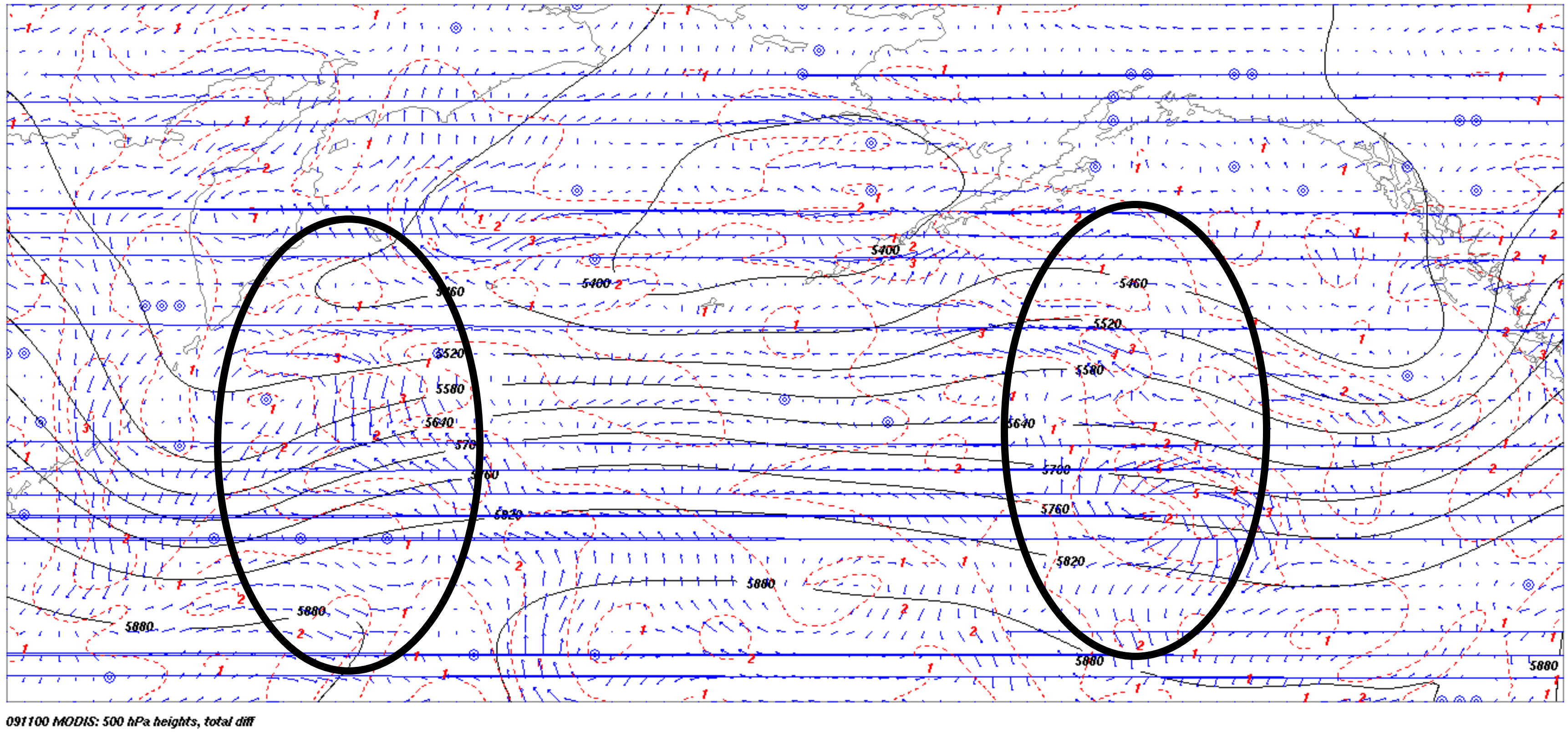
Percent of cases where the specified run had a more accurate hurricane position than the other run. Note: These cases are for hurricanes in the subtropics.

5. Analysis and forecast: Ageostrophic wind

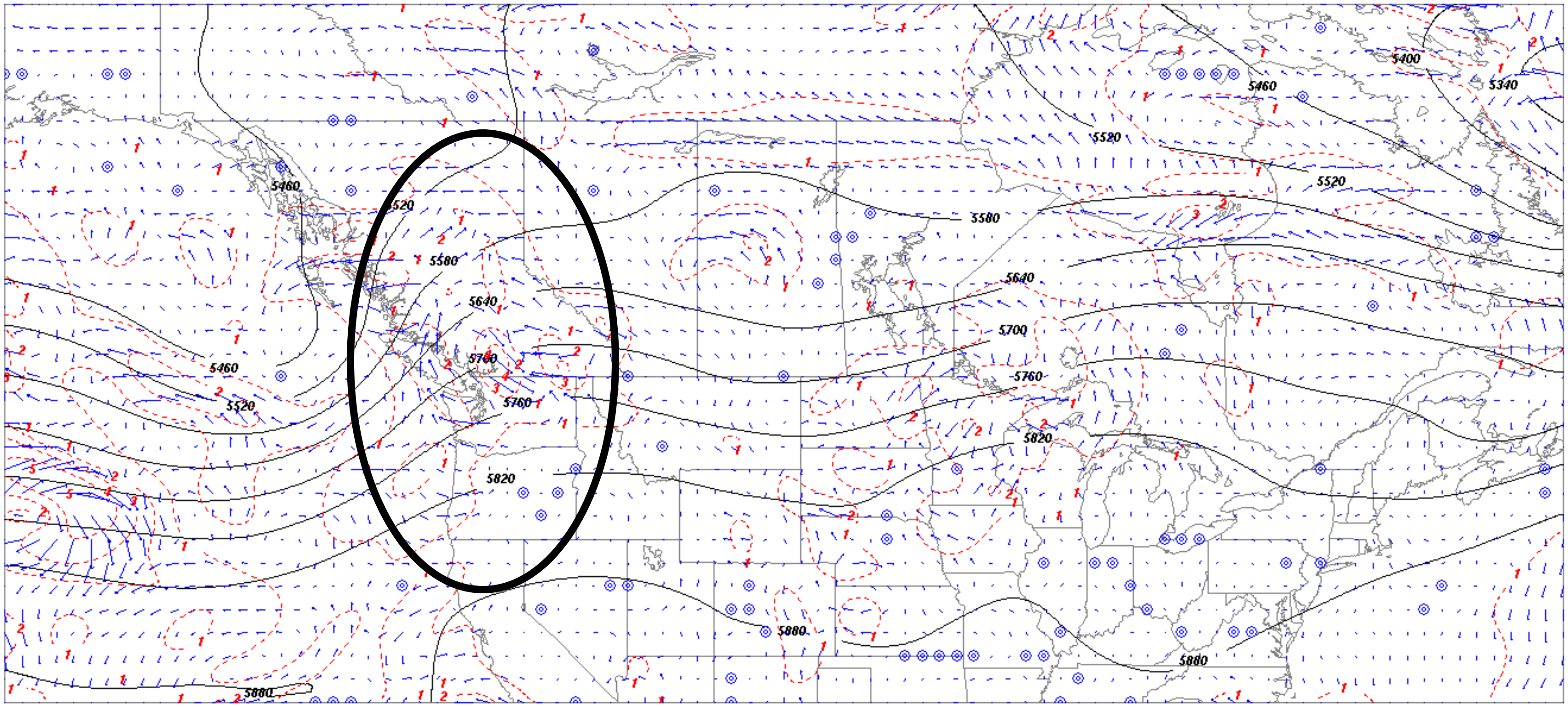
Compute the ageostrophic wind differences between the MODIS wind and control runs. Qualitatively examine how the propagation of these anomalies is reflected in the forecast height field.



091100 MODIS: 500 hPa heights, geo diff



Difference in the total wind (m s^{-1}) at 500 hPa between the MODIS winds and control model runs. Circles from previous figure. This is the analysis at 0000 GMT on 11 September 2004.



11

Difference in the total wind (m s^{-1}) at 500 hPa between the MODIS winds and control model runs. Circles from previous figure. This is the analysis at 0000 GMT on 11 September 2004.

Analysis

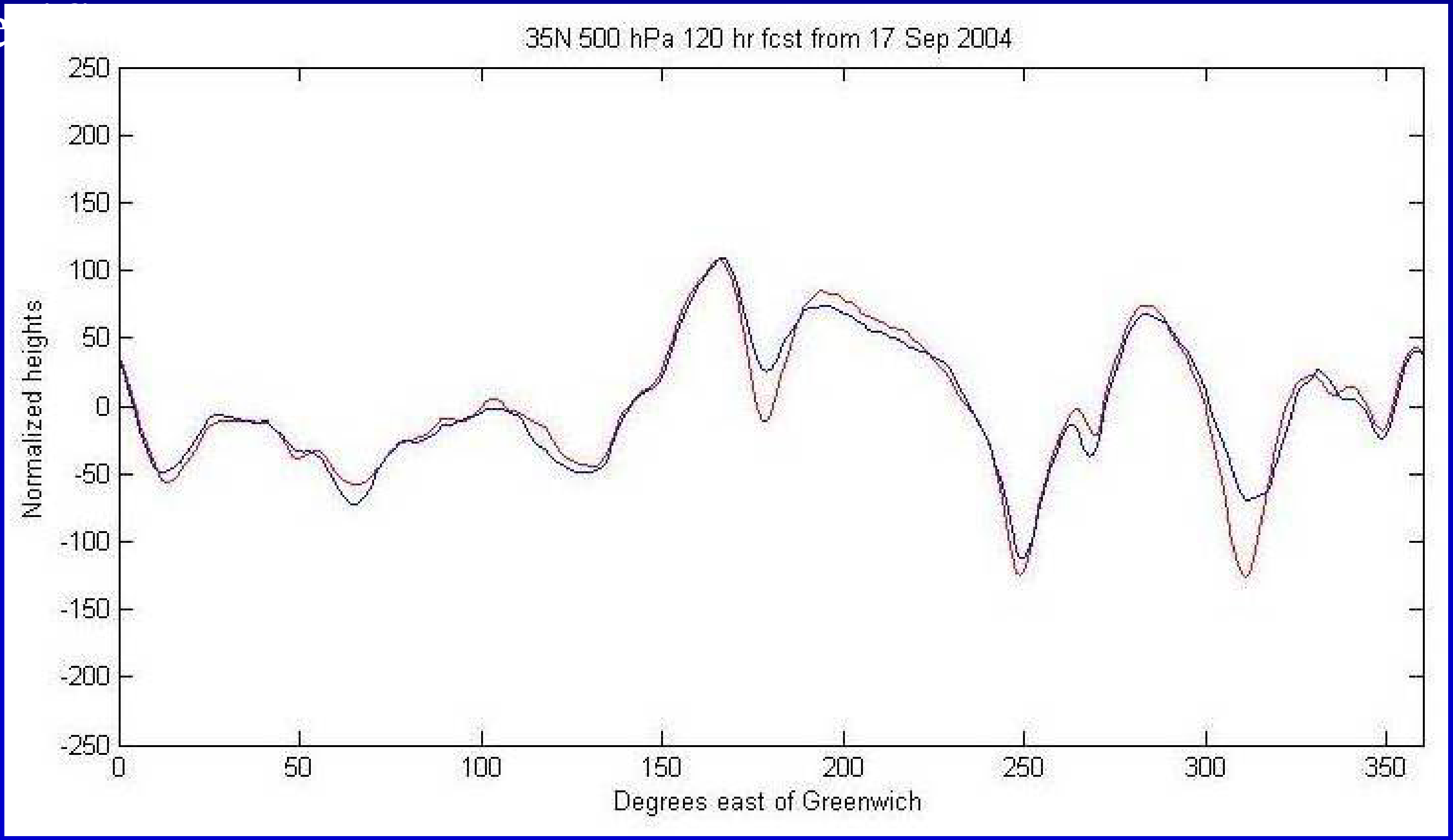
5. Analysis and forecast: Ageostrophic wind: Compute the ageostrophic wind differences between the MODIS wind and control runs. Qualitatively examine how the propagation of these anomalies is reflected in the forecast height field.

Analysis

5. Analysis and forecast: Ageostrophic wind: Compute the ageostrophic wind differences between the MODIS wind and control runs. Qualitatively examine how the propagation of these anomalies is reflected in the forecast height field.

6. Forecast impact: Phase shift in waves

Compute the correlation coefficient of the 500 hPa heights along a latitude circle for the 120-hour forecast time to determine the phase shift of the waves between the two model runs. This is computed for the entire latitude circle and for spe



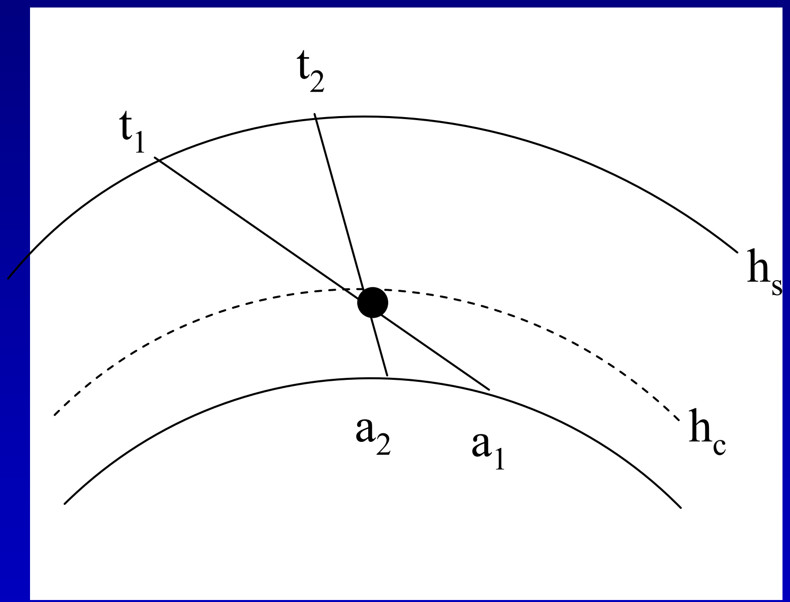
Analysis

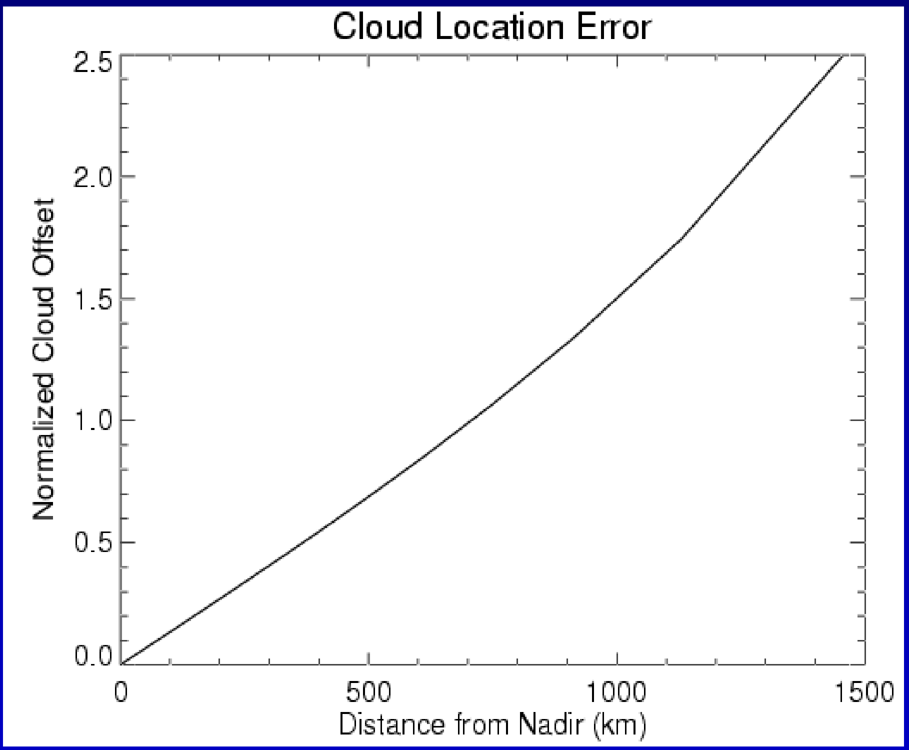
- Need to quantify how the difference in the divergence of the ageostrophic wind affects the speed of the waves.
- The divergence of the ageostrophic wind is related to the geostrophic vorticity advection.
- A difference in this quantity between the control and MODIS winds experiment should give an indication on a change in the propagation of troughs and ridges.

$$\nabla \bullet \vec{V}_a = -\frac{1}{f_0}\vec{V}_g \bullet \nabla \zeta$$

Parallax

Effect on Cloud Location:

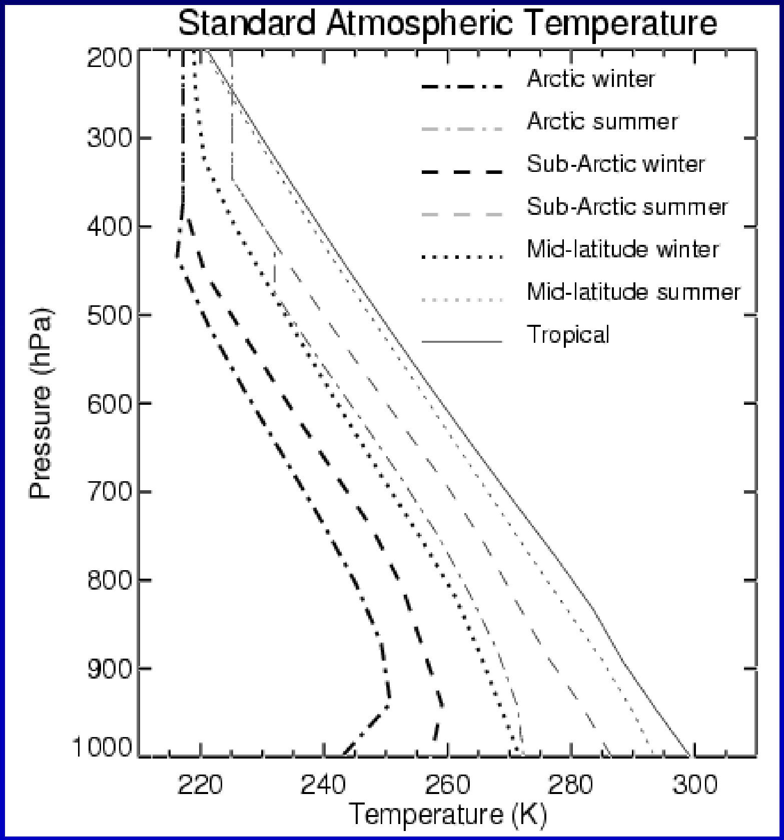




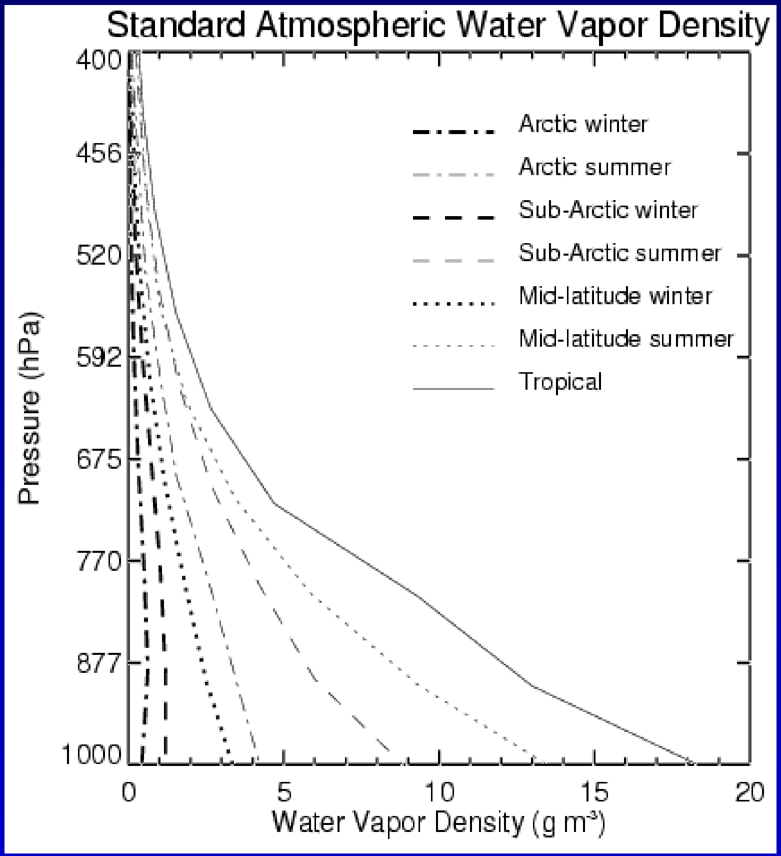
h_s is satellite height
h_c is cloud height
t is time
a is ground location

For a cloud of any given height, the error in cloud location is the height of the cloud multiplied by the normalized offset value. The direction of the apparent offset is directly away from the the satellite.

Polar Temperature and Water Vapor



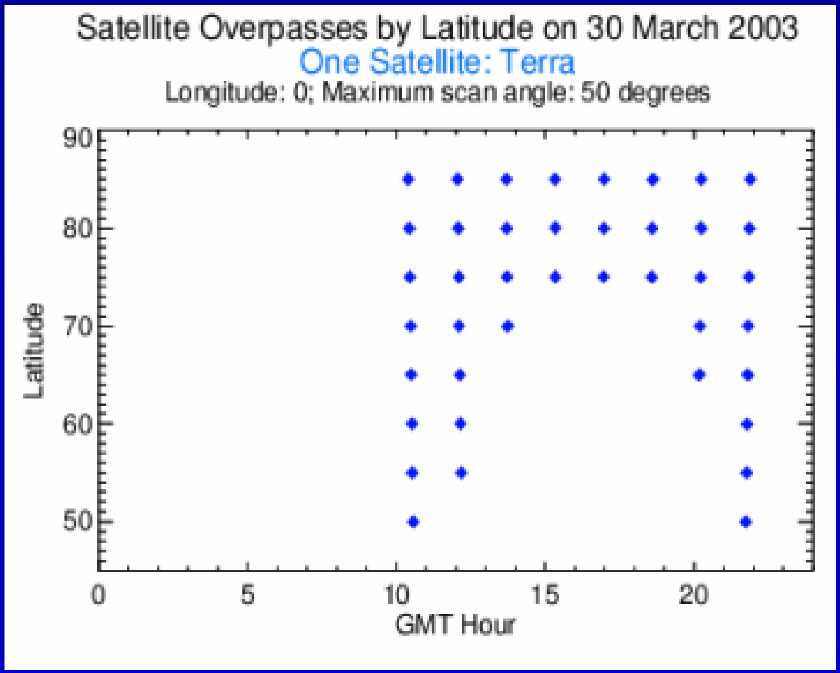
Standard atmosphere temperature profile from the tropics to the Arctic. Note the significant inversion in the Arctic and sub-Arctic winter.

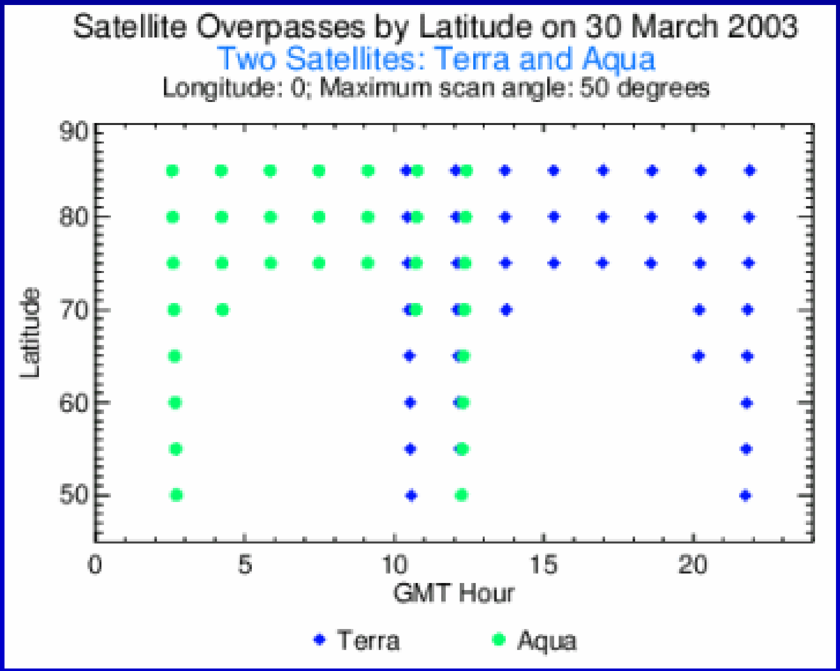


Standard atmosphere water vapor density profile from the tropics to the Arctic.

Overpass Frequency

The lower-left figure shows the time of successive overpasses at a given latitude-longitude point on a single day with only the Terra satellite. The figure in the lower right shows the frequency of "looks" by two satellites: Terra and Aqua.



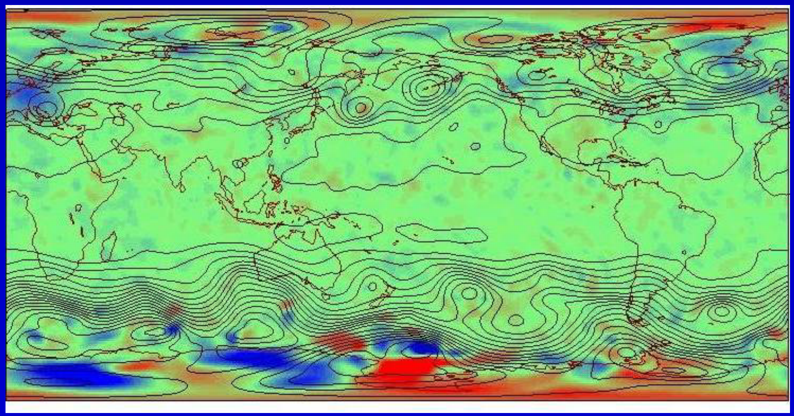


Operational Use

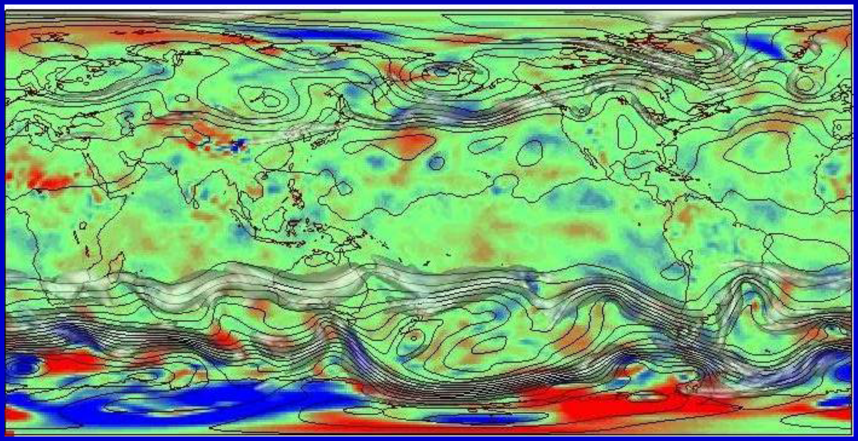
NWP Site	Operational Begin Date
ECMWF European Centre for Medium-Range Weather Forecasts	January 2003
GMAO Global Modeling and Assimilation Office	Unknown
JMA Japan Meteorological Agency	May 2004
CMC Canadian Meteorological Centre	September 2004
FNMOC US Navy, Fleet Numerical Meteorology and Oceanography Center	October 2004
Met Office United Kingdom	January 2005
NCEP	November 2005
DWD Deutscher Wetterdienst	Early 2006
NCAR Antarctic Mesoscale Model (AMPS)	2005

The NOGAPS and AMSU Experiments

1. NOGAPS thickness difference features are smoother: NAVDAS creates “super observations”
2. NOGAPS differences are larger over the poles: different weights.
3. NOGAPS differences are not as far south in the analysis: spectral vs. grid point assimilation.

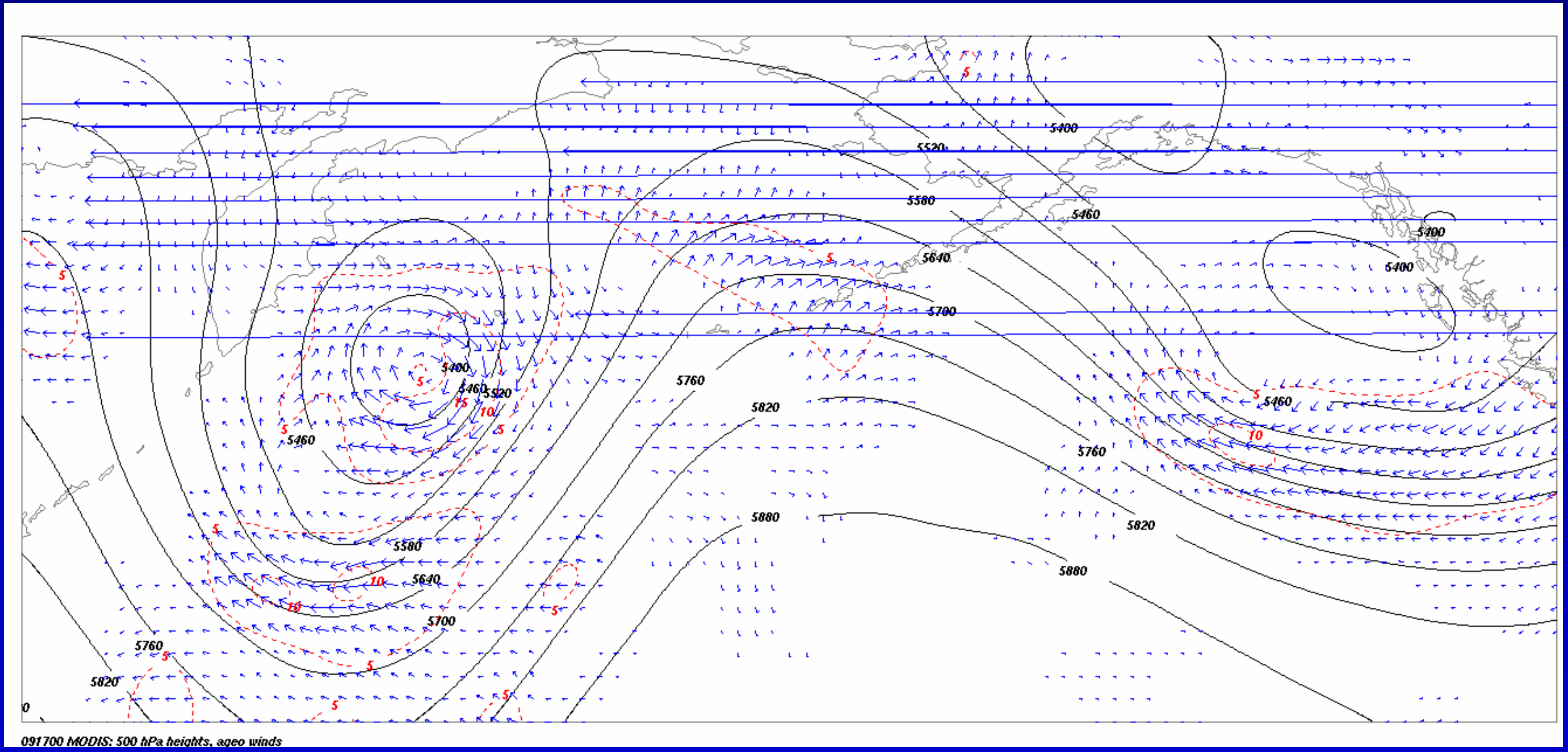


1. AMSU thickness difference features are larger: higher weight and global data.
2. MODIS winds still have positive impact: may provide non-balanced wind information over the thermally balanced radiances.



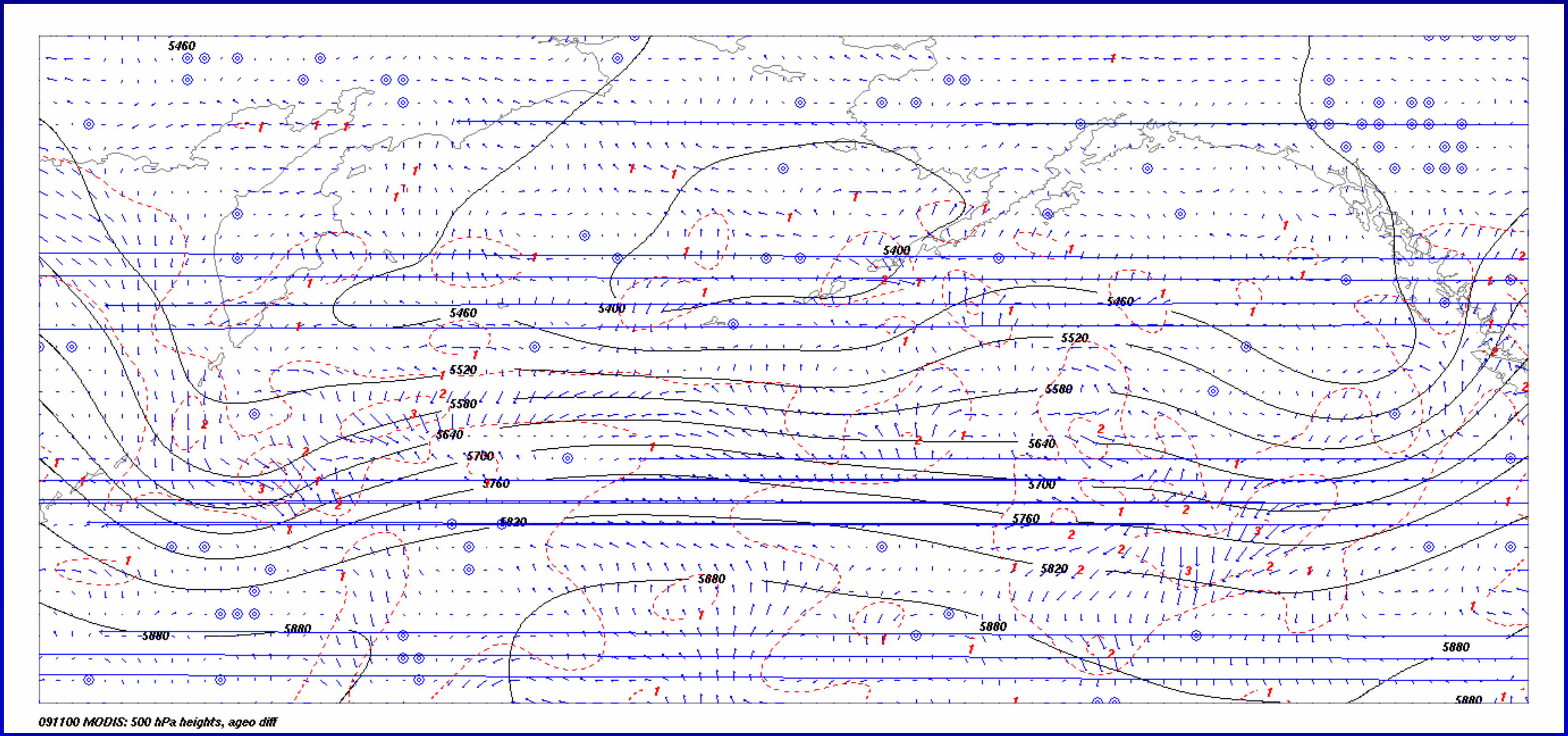
5. Analysis and forecast: Ageostrophic wind

Computed ageostrophic wind from model output grids.



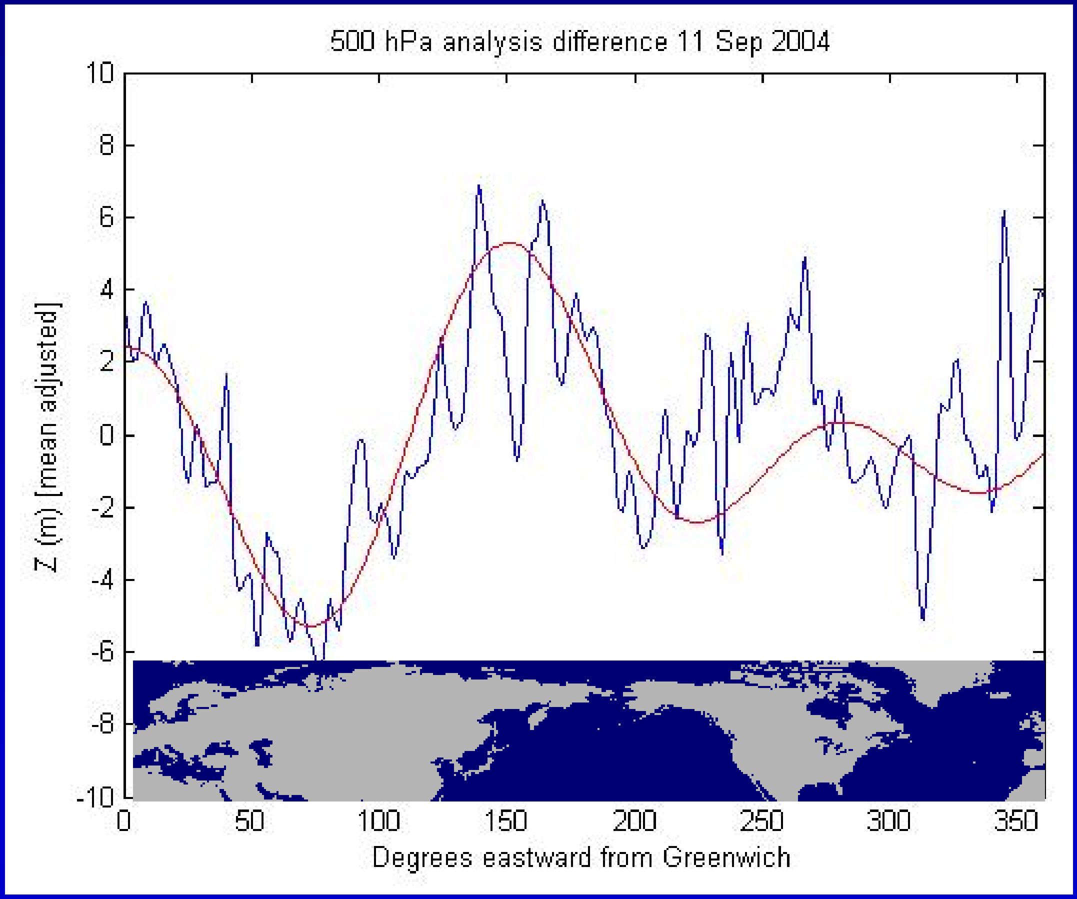
5. Analysis and forecast: Ageostrophic wind

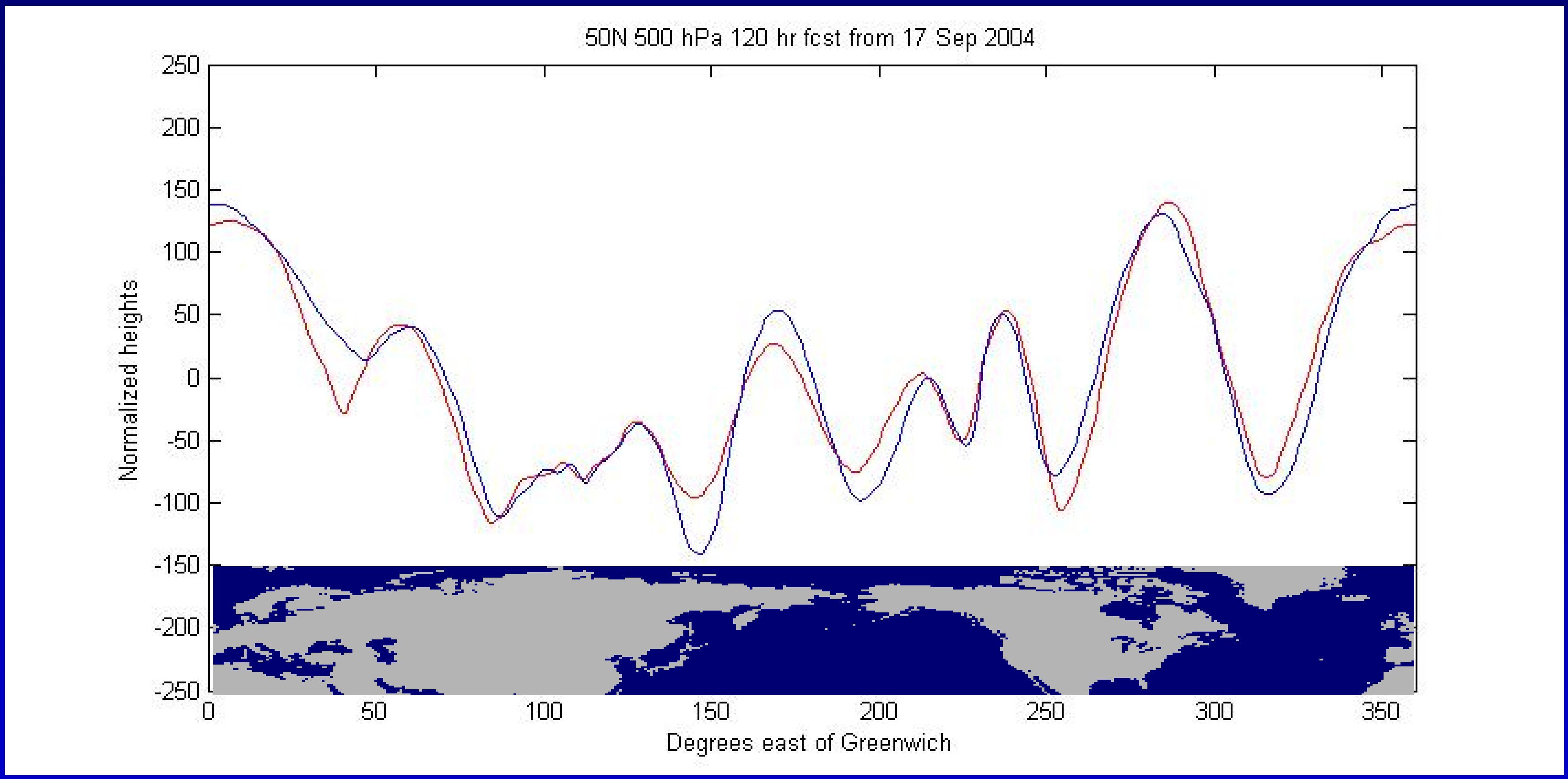
Difference in the ageostrophic wind between the two model analyses.

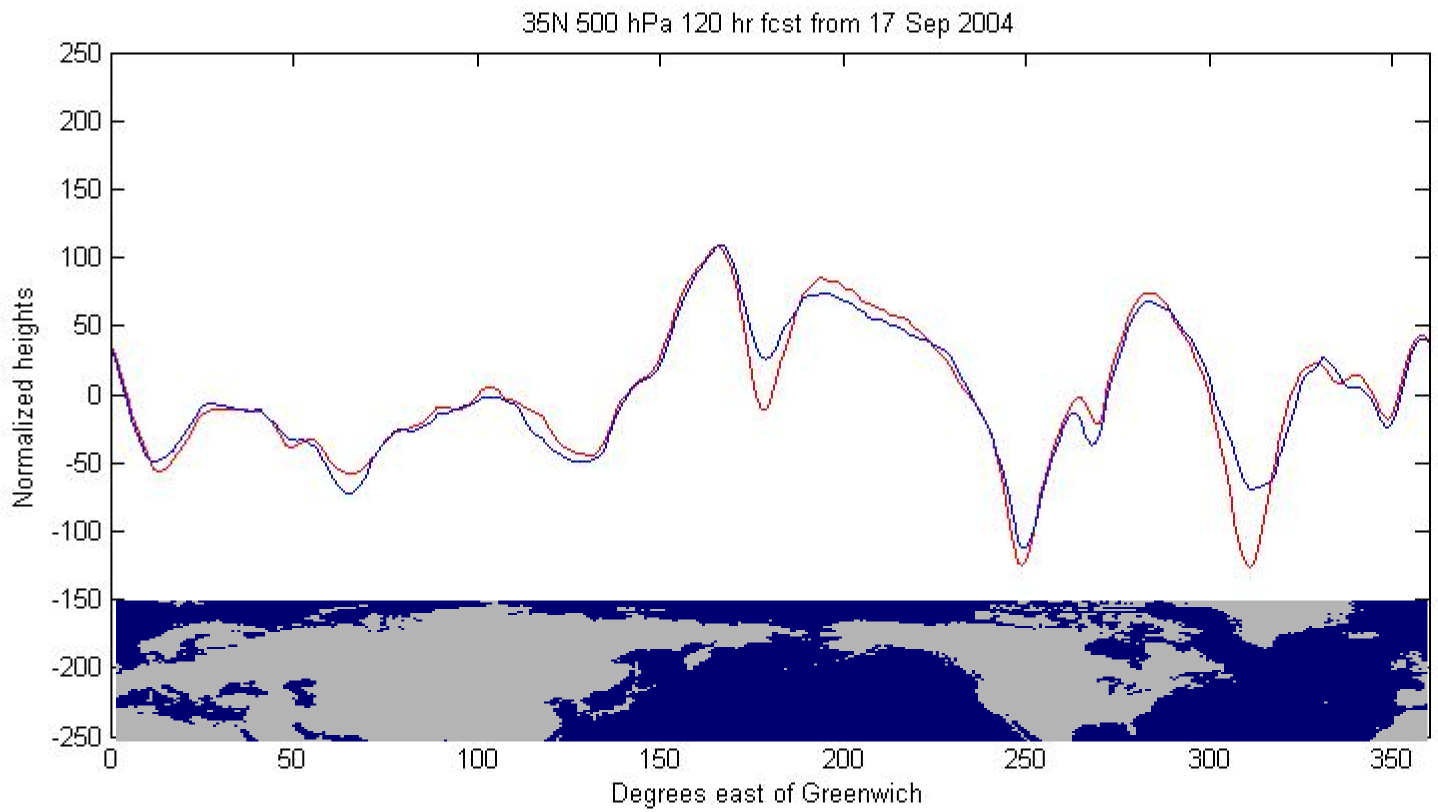


3. Analysis impact: Geographic

A cross-section of 500 hPa height differences along a latitude circle at the analysis times are used to determine where the MODIS had the largest impact, geographically.




50N 500 hPa 120 hr fcst from 17 Sep 2004
Normalized heights
250
200
150
100
50
0
-50
-100
-150
-200
-250
0
50
100
150
200
250
300
350
Degrees east of Greenwich



35N 500 hPa 120 hr fcst from 17 Sep 2004
Normalized heights
250
200
150
100
50
0
-50
-100
-150
-200
-250
0
50
100
150
200
250
300
350
Degrees east of Greenwich

3. Analysis impact: Geographic

A qualitative summary of the largest impact by longitude. Large is defined as +/- 4 gpm from the normalized mean. Generally, the range is +/- 6 gpm.

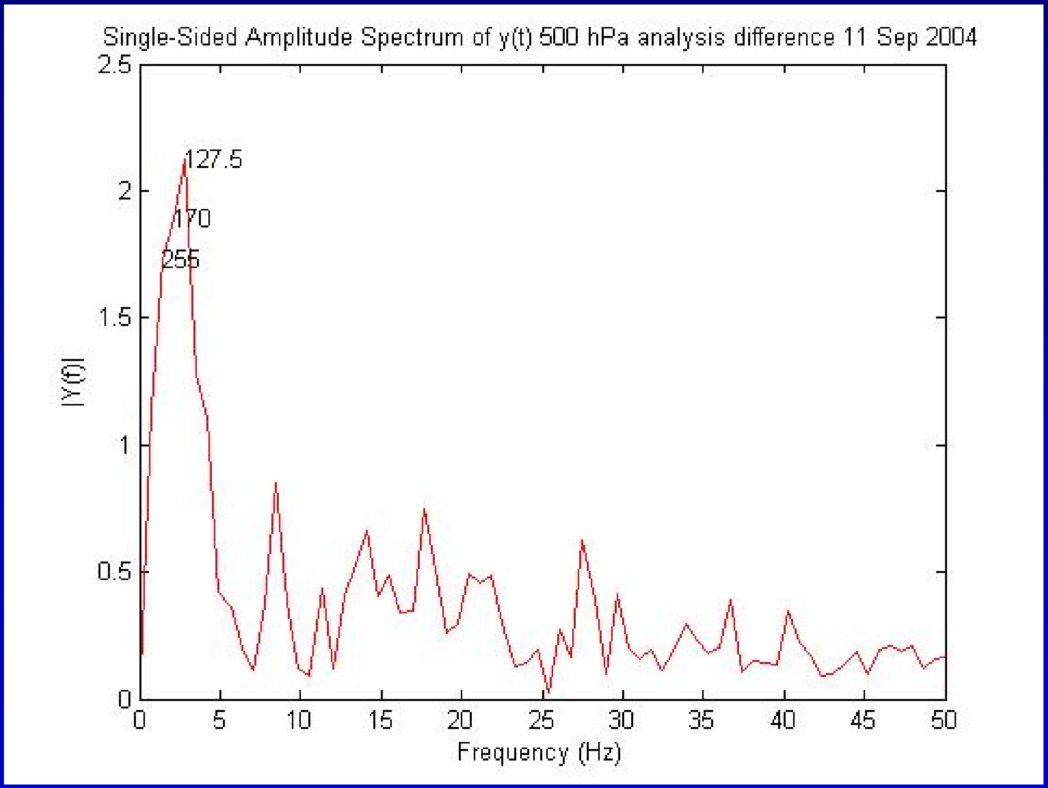
Date\Longitude	50°E W. Asia	180°E N. Pacific	90°W Mid USA	30°W N. Atlantic
06 Sep 2004	T	X_T	X_T	X_T
07 Sep 2004	X_T	X_Z	T	X_T
11 Sep 2004	X_T	X_T	X_Z	X_T
12 Sep 2004	X_T	X_T	Z	X_T
17 Sep 2004	R	X_T	Z	X_T

X indicates a large difference, with a subscript indicating the type of flow: T - Trough, R – Ridge, Z - Zonal flow.

3. Analysis impact: Geographic

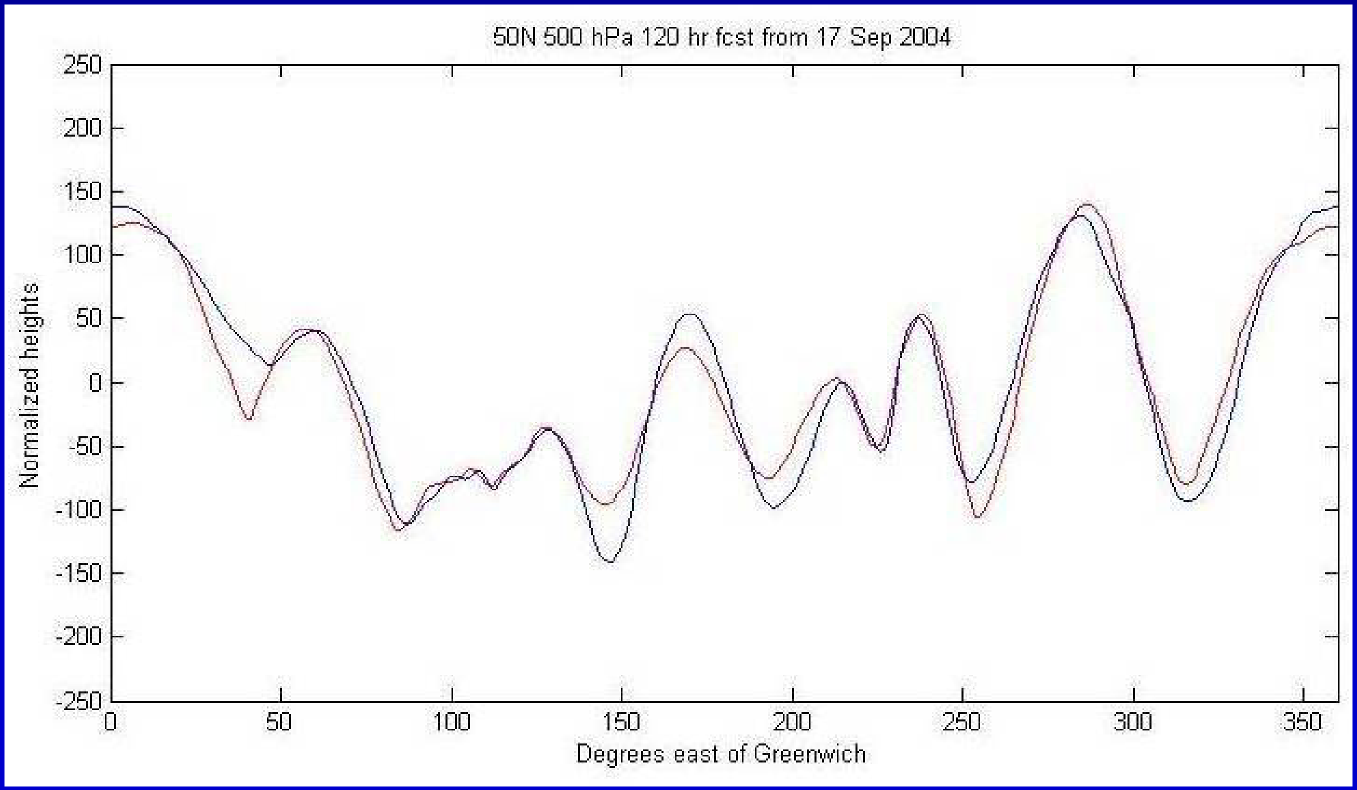
This is quantified by computing the power spectra in geographic space.

The power spectra for the five cases show preferred wavelengths of 128 and 170 degrees; having one of the highest three amplitudes on all days, with both frequencies on three out of five days.



6. Forecast impact: Phase shift in waves

Compute the correlation coefficient of the 500 hPa heights along a latitude circle for the 120-hour forecast time to determine the phase shift of the waves between the two model runs. This is computed for the entire latitude circle and for specific waves.



6. Forecast impact: Phase shift in waves

Compute the correlation coefficient of the 500 hPa heights along a latitude circle for the 120-hour forecast time to determine the phase shift of the waves between the two model runs. This is computed for the entire latitude circle and for specific waves.

	50 N (deg. Long.)	50 N (km)	35 N (deg. Long.)	35 N (km)
06 Sep 04	+0.5	+35	-0.07	-6
07 Sep 04	-0.4	-31	-0.5	-49
11 Sep 04	-0.4	-30	-0.5	-49
12 Sep 04	-1.0	-74	+0.4	+33
17 Sep 04	-0.4	-28	-0.9	-85

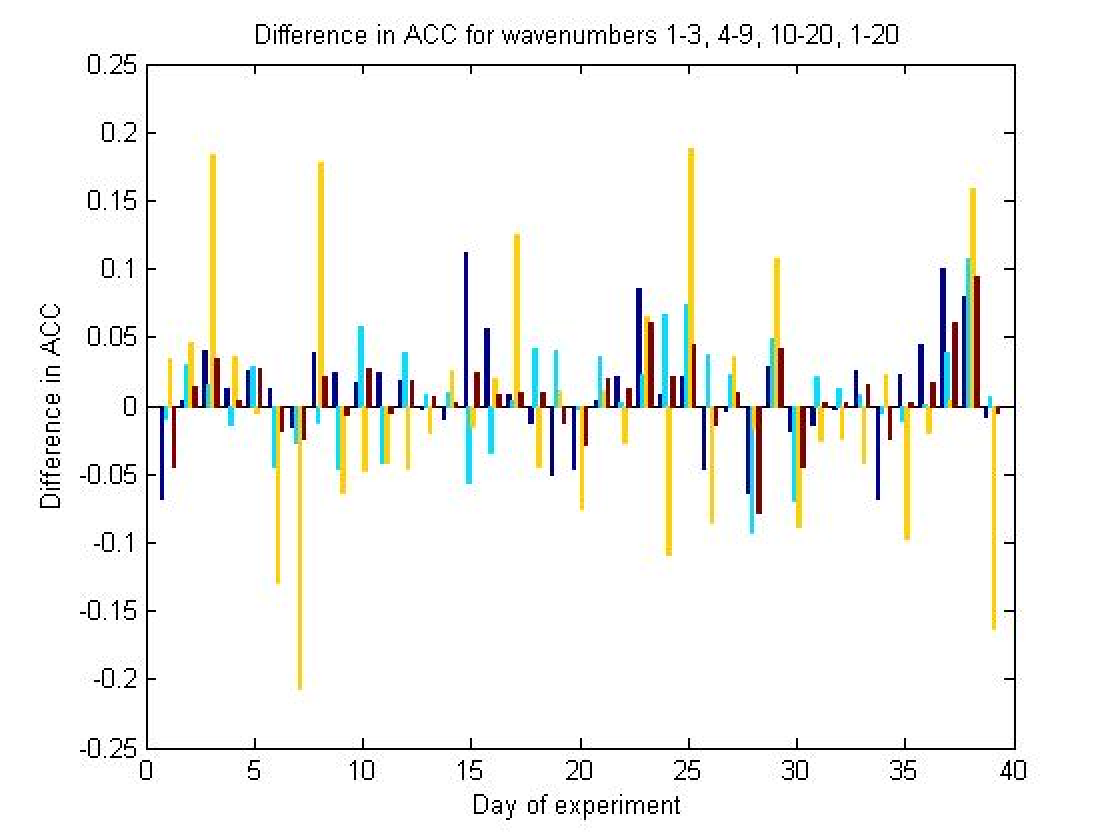
2. Forecast impact: Wavelength

Difference in ACC between MODIS and control model run for the 120-hour forecast at 500 hPa in the northern hemisphere.

Wavenumber by color:
Blue: 1 - 3
Cyan: 4 - 9
Yellow: 10 - 20
Red: 1 – 20

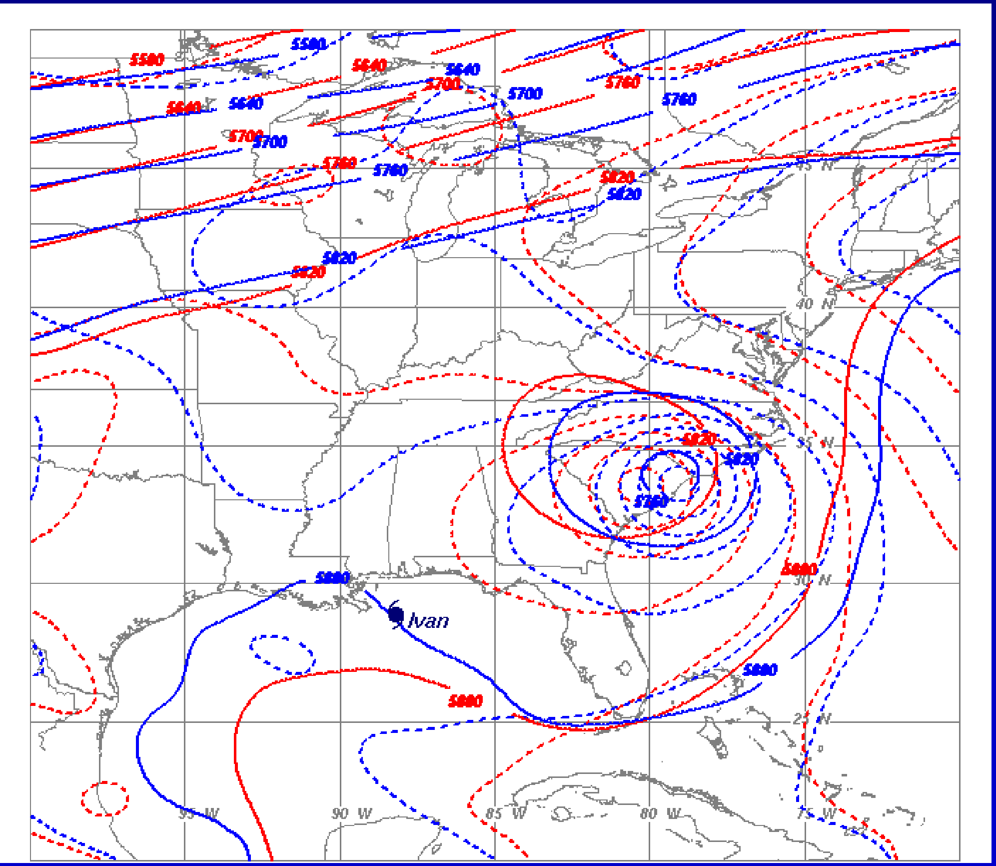
4 to 9 wavenumbers is a wavelength of 1500 to 3000 km in the mid-latitudes.

70% of the days are neutral or improved with the MODIS winds.



7. Forecast impact: Tropical cyclone positions

Determine the position of the tropical cyclones in the 120-hour forecasts vs. the actual location. Show how a change in the speed of mid-latitude systems may affect these forecast positions.



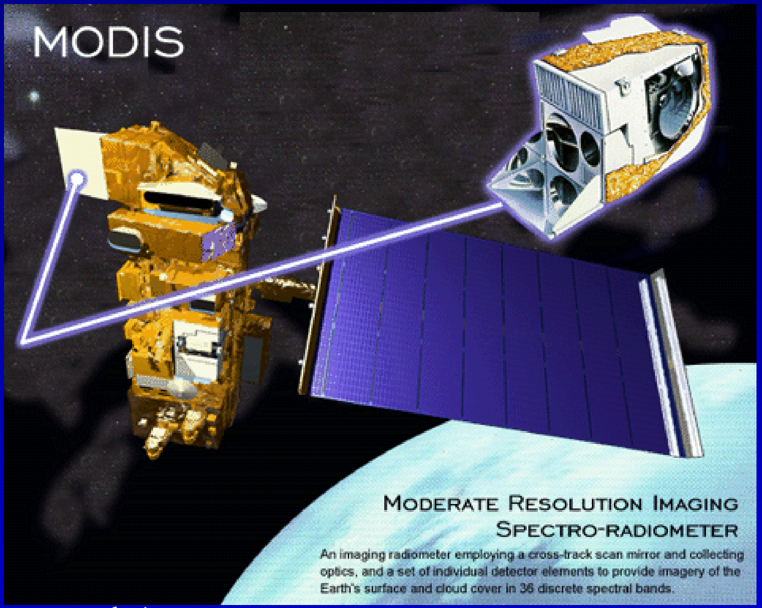
7. Forecast impact: Tropical cyclone positions

Determine the position of the tropical cyclones in the 120-hour forecasts vs. the actual location. Show how a change in the speed of mid-latitude systems may affect these forecast positions.

Forecast time:	96 hours	120 hours
Ivan 11 September 2004	27	54
Ivan 12 September 2004	n/a	-108
Karl 17 September 2004	129	30

MODIS Instrument

- Moderate Resolution Imaging Spectroradiometer
- Terra and Aqua satellites
  - 700 km orbit
  - Sun-synchronous
- 36 channels: 0.4 to 14.4 µm
- 250m to 1000m pixel size
- Scans +/- 55 deg (2300 km swath)



Validation of MODIS Winds

Comparison (m s^{-1}) of Terra MODIS WV satellite winds to rawinsondes. Northern Hemisphere: 4,600 samples in December 2006.

All levels	Satellite wind	Guess wind
NRMS difference	0.44	0.41
RMS difference	6.79	6.37
Average difference	5.64	5.25
Standard deviation	3.79	3.61
Speed bias	-0.43	-1.03
Average Speed	15.19	14.59

Comparison (m s^{-1}) of GOES-12 WV satellite winds to rawinsondes. Northern Hemisphere: 20,300 samples in December 2006.

All levels	Satellite wind	Guess wind
NRMS difference	0.28	0.24
RMS difference	7.72	6.80
Average difference	6.35	5.53
Standard deviation	4.40	3.96
Speed bias	-0.07	-1.12
Average Speed	27.97	26.91

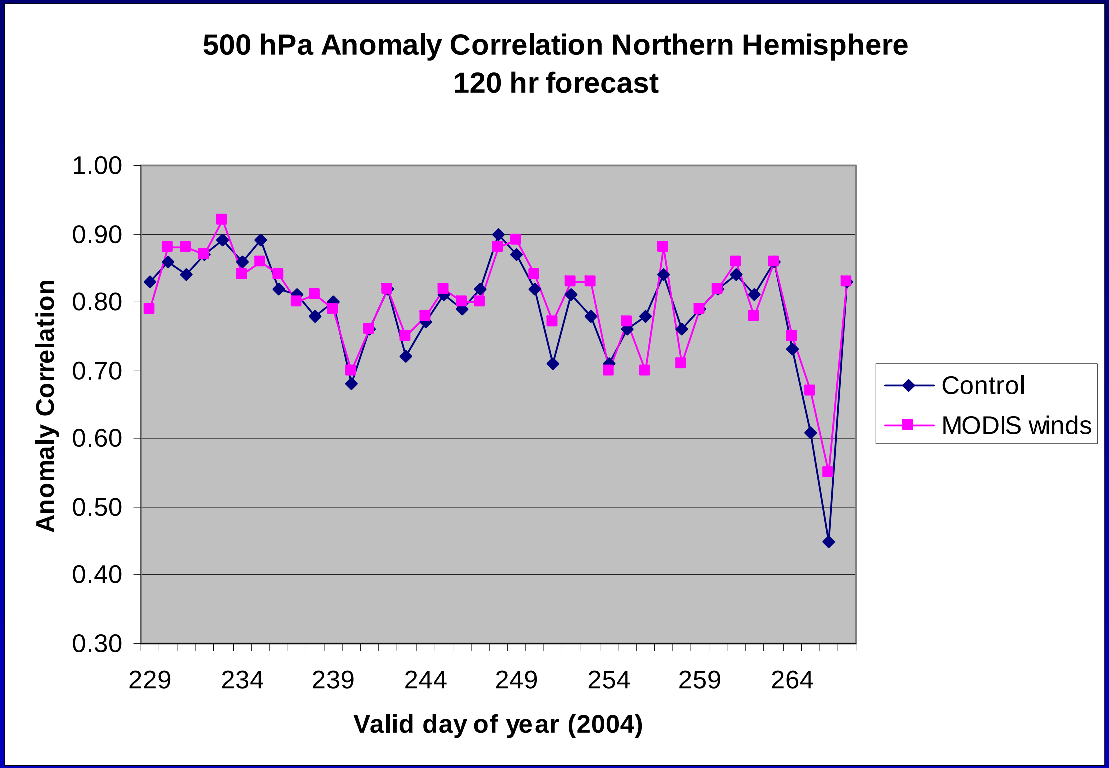
$$Vdiff = \sqrt{(\overline{u} - u)^2 + (\overline{v} - v)^2}$$

$$RMS = \sqrt{Vdiff_{mean}^2 + Vdiff_{std}^2}$$

$$NRMS = RMS / S_{avg}$$

GFS Model Impact: Daily ACC

ACC as a function of day for the 120-hour forecast of the geopotential at 500 hPa. Period is 11 August to 22 September 2004. Forecast scores are the correlation between the forecast geopotential height anomalies, with and without the MODIS winds, and their own analyses. This is for the Northern Hemisphere.



The Experiment

Five cases chosen based on ACC score and significant weather event.

Day	MODIS ACC	Control ACC	Number of winds	Comments
06 Sep 2004	0.77	0.76	21,300	ACC similar
07 Sep 2004	0.71	0.78	12,271	MODIS ACC worse
11 Sep 2004	0.82	0.82	15,075	Hurricane Ivan
12 Sep 2004	0.86	0.84	7,115	ACC similar
17 Sep 2004	0.55	0.45	15,303	Forecast bust Hurricane Karl

Rossby Wave Speed

$$c_x = \bar{u} - \left(\beta / K^2\right)$$

u is the mean zonal wind speed

β is the earth's vorticity gradient

K is the total horizontal wave number: $K^2 = (l^2 + k^2)$; wavenumbers k and l are equal to 2π/wavelength.

For example, a 6000 km wave at 50°N latitude ($\beta = 1.4e^{-11} m^{-1} s^{-1}$), the zonal wave speed is about 7 m s^{-1} slower than the mean zonal wind speed.

To effect a 1 m s^{-1} change in wave speed (430 km displacement in five days) the:

- mean zonal wind would need to change by 1 m s^{-1}
- the wavelength by 500 km, or
- some combination.

Analysis and forecast: Thickness difference

The following figures depict the thickness difference between the control and MODIS winds model runs. The colors represent the differences -30 to +30 gpm ranging from blue to red. Blue indicating that the addition of the MODIS winds resulted in a lower thickness (cooling).

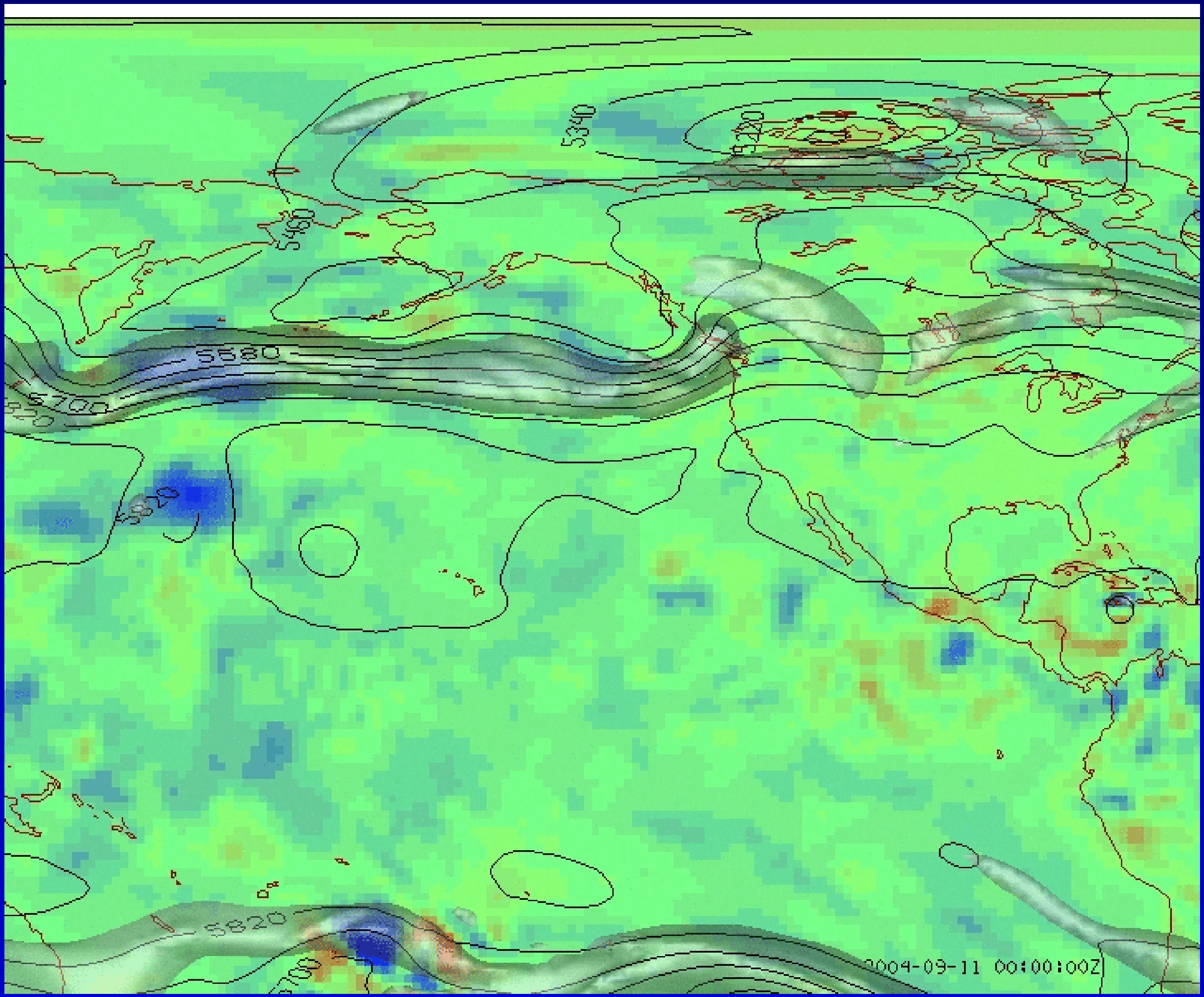
The position of the differences can be interpreted, thus:

- When a difference feature is centered on a ridge or trough, it indicates a change in the amplitude of the wave.
- When the difference feature is displaced from a ridge or trough, it indicates a phase shift.

1000-500 hPa Thickness Differences

1000-500 hPa thickness difference between control and MODIS winds analyses on 11 Sep 2004.

The range from blue to red is from -30 to +30 gpm difference. Near zero difference in green. 500 hPa height contours in black. 30 m/s wind speed in transparent white.

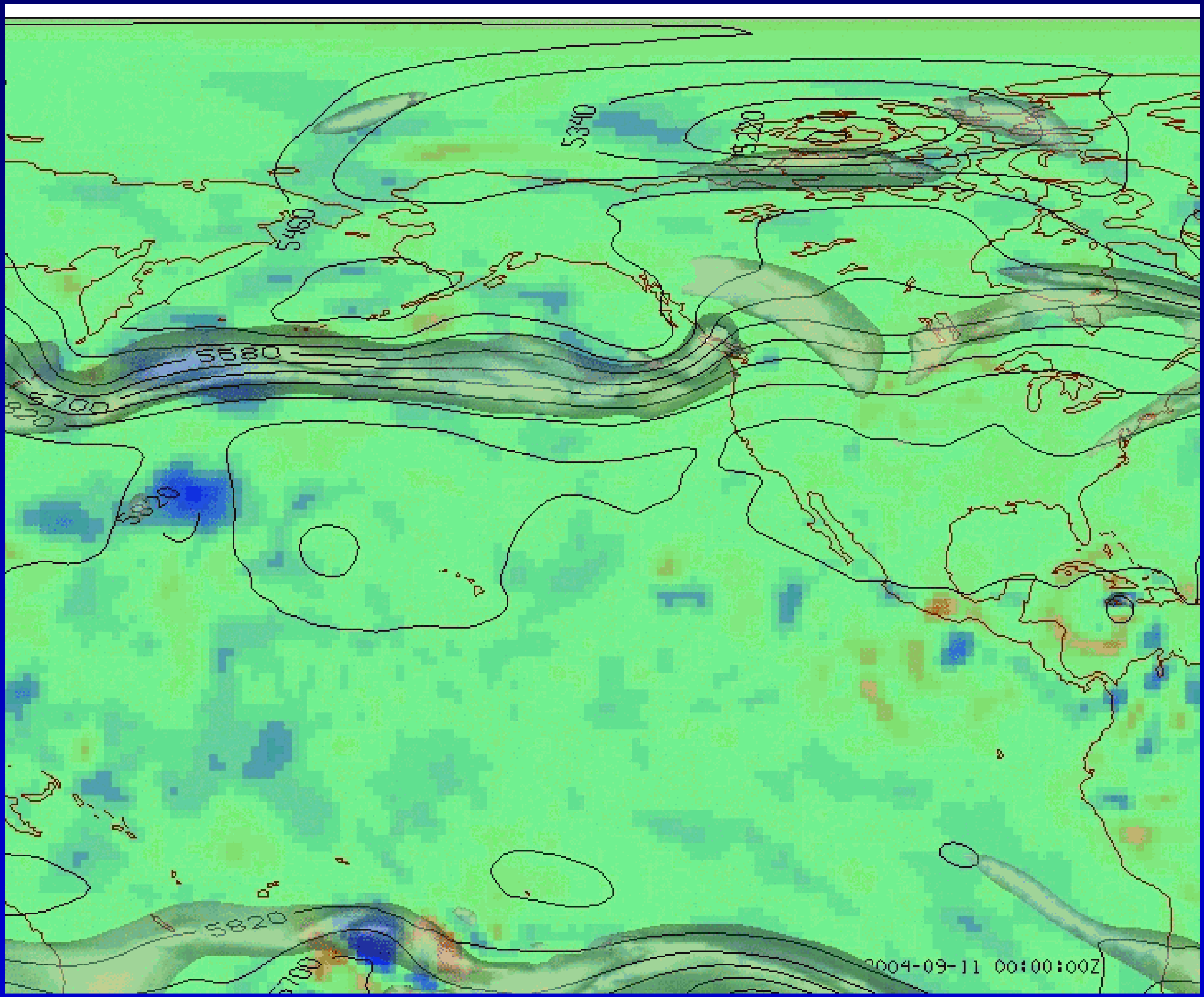


Effects into the Mid- and Low-Latitudes

Parameters and colors same as the previous figure.

Depiction of the forecasts out to 5 days in 6-hour timesteps.

The thickness difference increases over the forecast cycle.

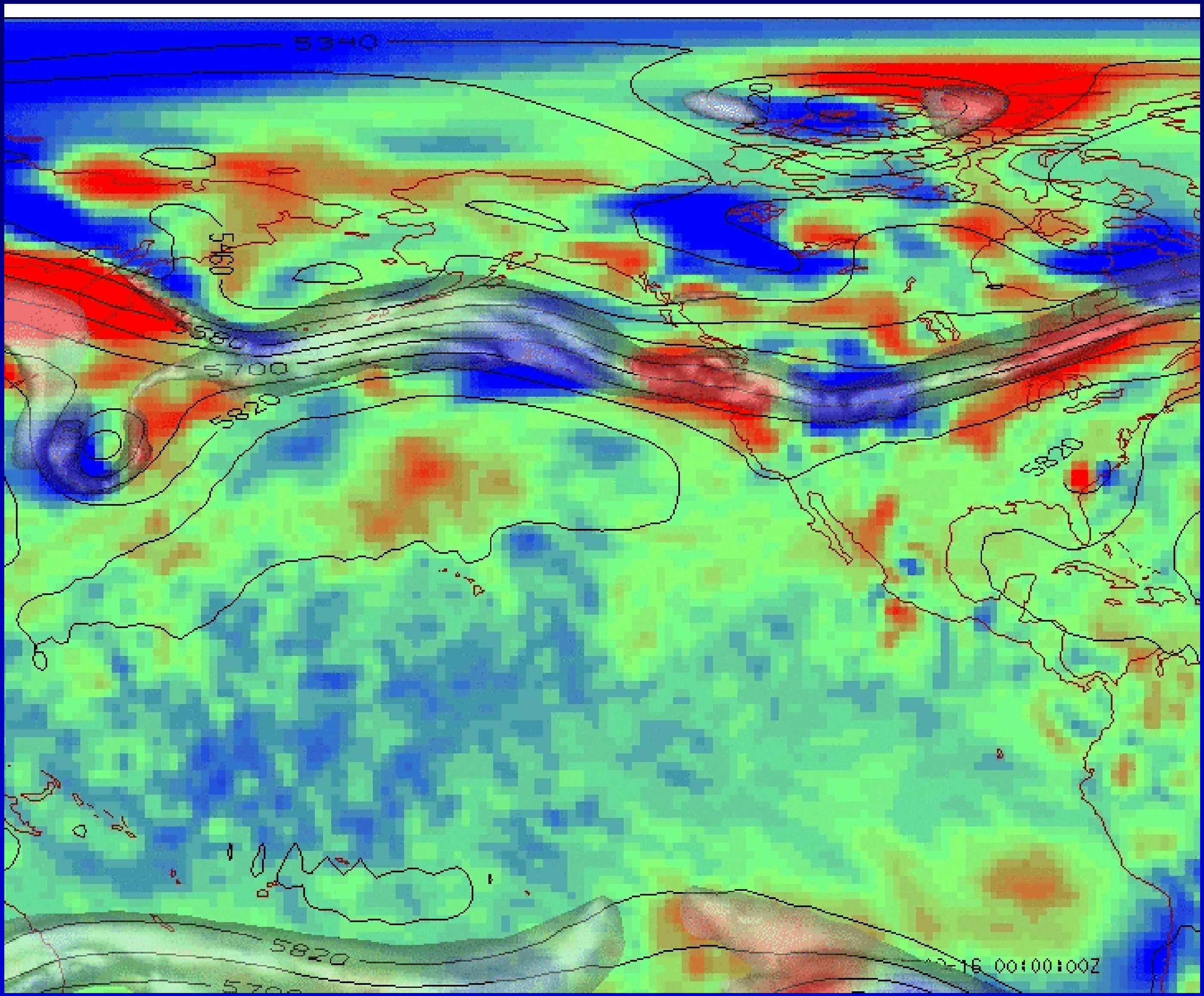


Effects into the Mid- and Low-Latitudes

Parameters and colors same as the previous figure.

This is the 120 hour forecast.

Alternating red and blue indicates differences in positions and/or intensities of troughs/ridges.



Conclusions

- In the model analysis, the mass adjustment required due to the addition of the MODIS winds results in a change to both the geostrophic and ageostrophic winds on the order of 5 m s^{-1} in the vicinity of the jet stream.

Conclusions

- The addition of the MODIS winds results in an average change to the 500 hPa wave propagation on the order of 0.5 to 1 degree of longitude over a 120-hour forecast for latitude bands 50°N and 35°N.
- The impact is much larger (up to 2 degrees of longitude or nearly 200 km) for specific waves.
- In 8 out of 10 instances (from 2 latitude bands for 5 cases) the addition of the MODIS winds slowed the northern hemisphere wave progression as evident in the 120-hour forecasts. Interestingly, although perhaps coincidentally, this agrees with Francis (2002) that the zonal flow in the arctic region was too fast, westerly, in the model reanalysis fields.

Conclusions

- Synoptic-scale waves in the vicinity of hurricanes Ivan and Karl were slowed (by 100 km and 200 km, respectively) with the addition of the MODIS winds, allowing these hurricanes to track further west in the 120-hour forecasts. These new positions were an improvement in the forecast.