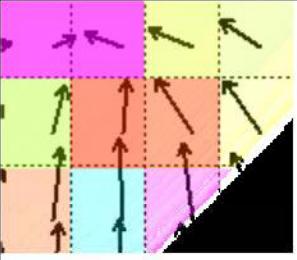


Storm Visualization using Tensor Field Analysis

Alex Naegele, Ohio State University

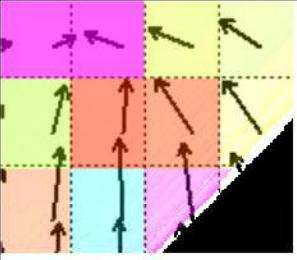
Ray Navarrete, University of Arizona

Andrew Zdyrski, University of Hawaii at Hilo



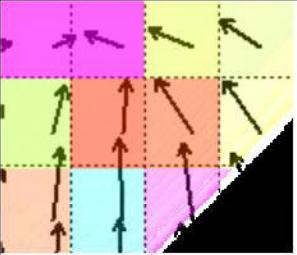
Overview

- I. Motivation
- II. Tensor Field Analysis
- III. Visualization
- IV. Storm Analysis



Objective

To create a visualization of the trajectory of a given storm event over time, in relation to aspects of air mass characteristics including stretching, scaling, and vorticity.



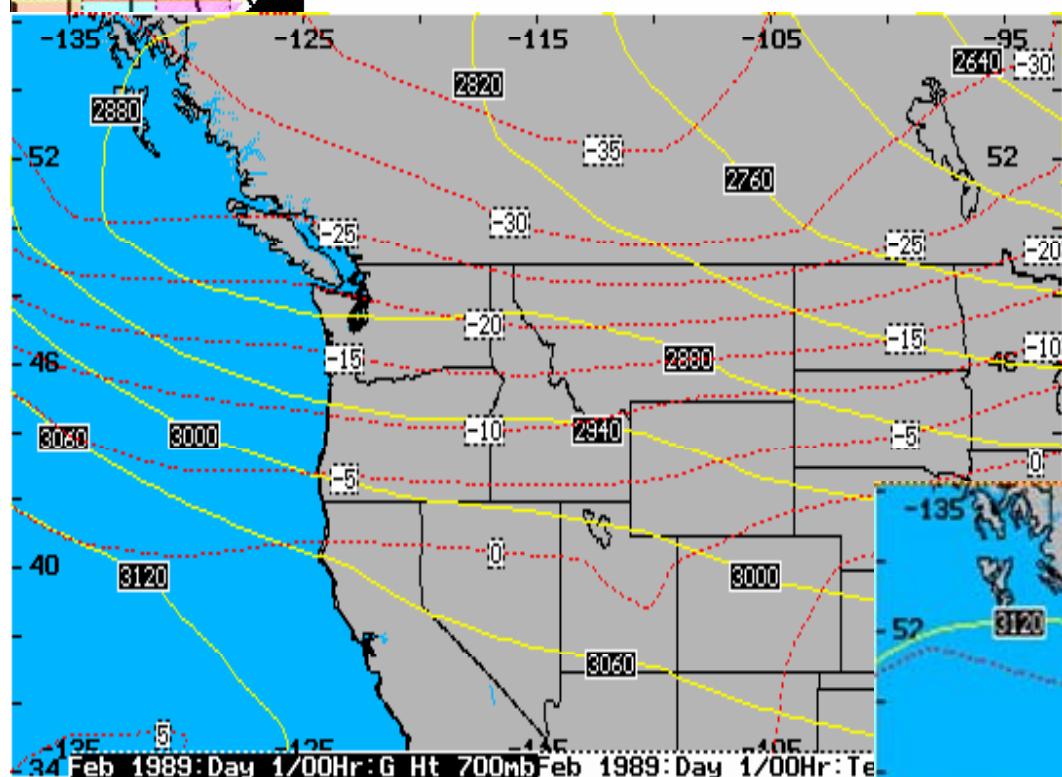
Introduction

- Applying tensor field visualizations to velocity vector field of a storm
- Visualized components of a storm's spatial distortion

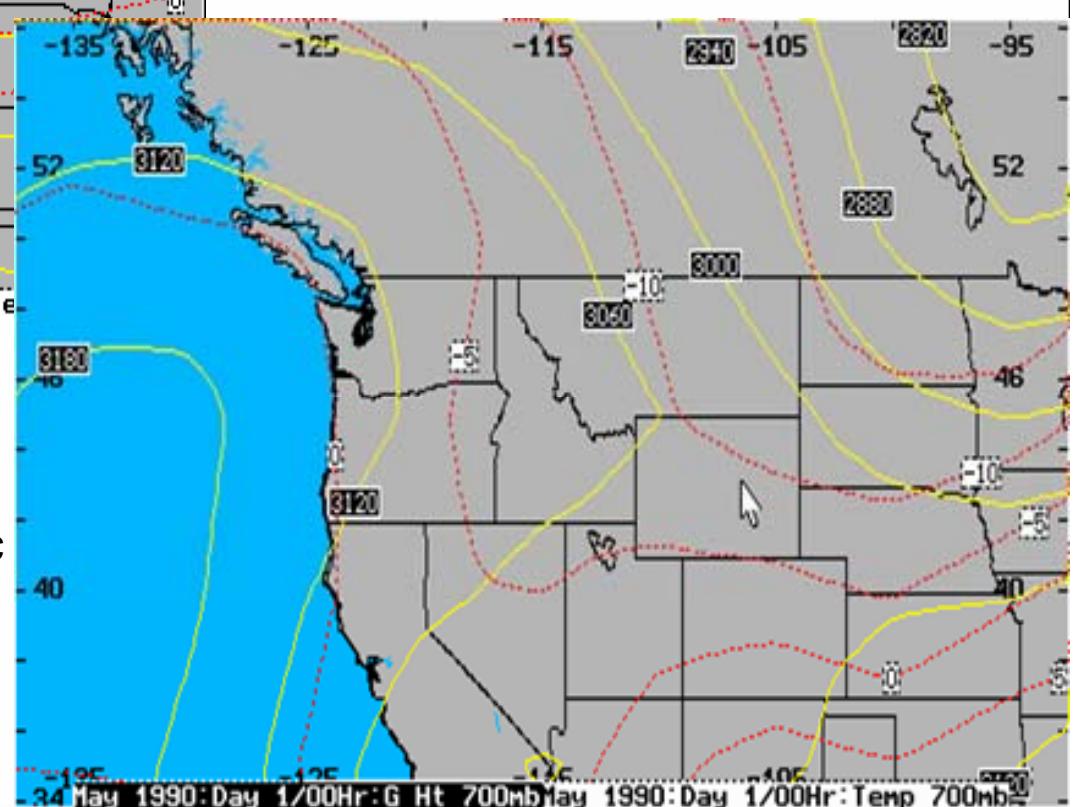
Climatological Background

Flow Curvature Types

Zonal Flow

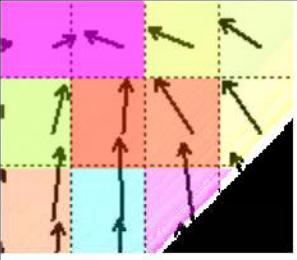


Cyclonic

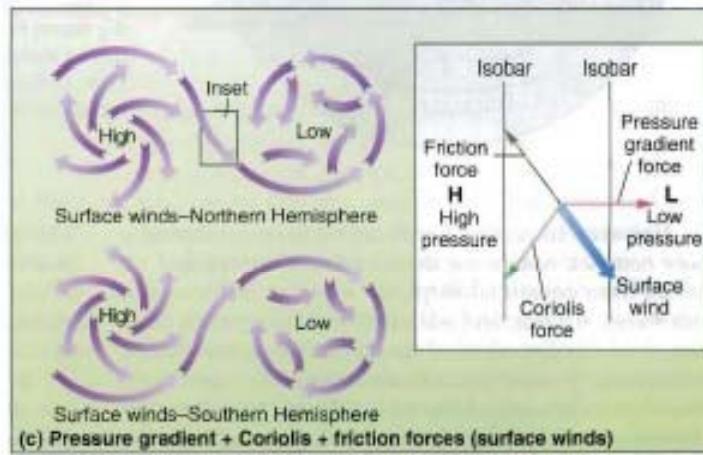
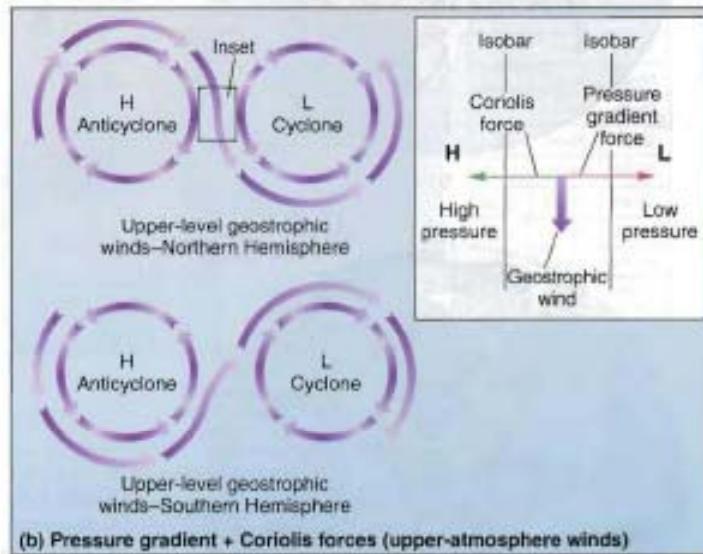
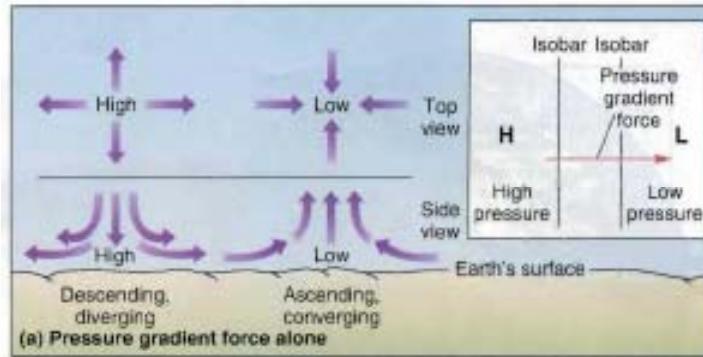


Anti-cyclonic

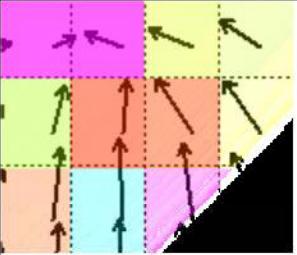
Source: Daly, Christopher. Hidden Climate Variability in Mountainous Terrain.



Atmospheric Circulation

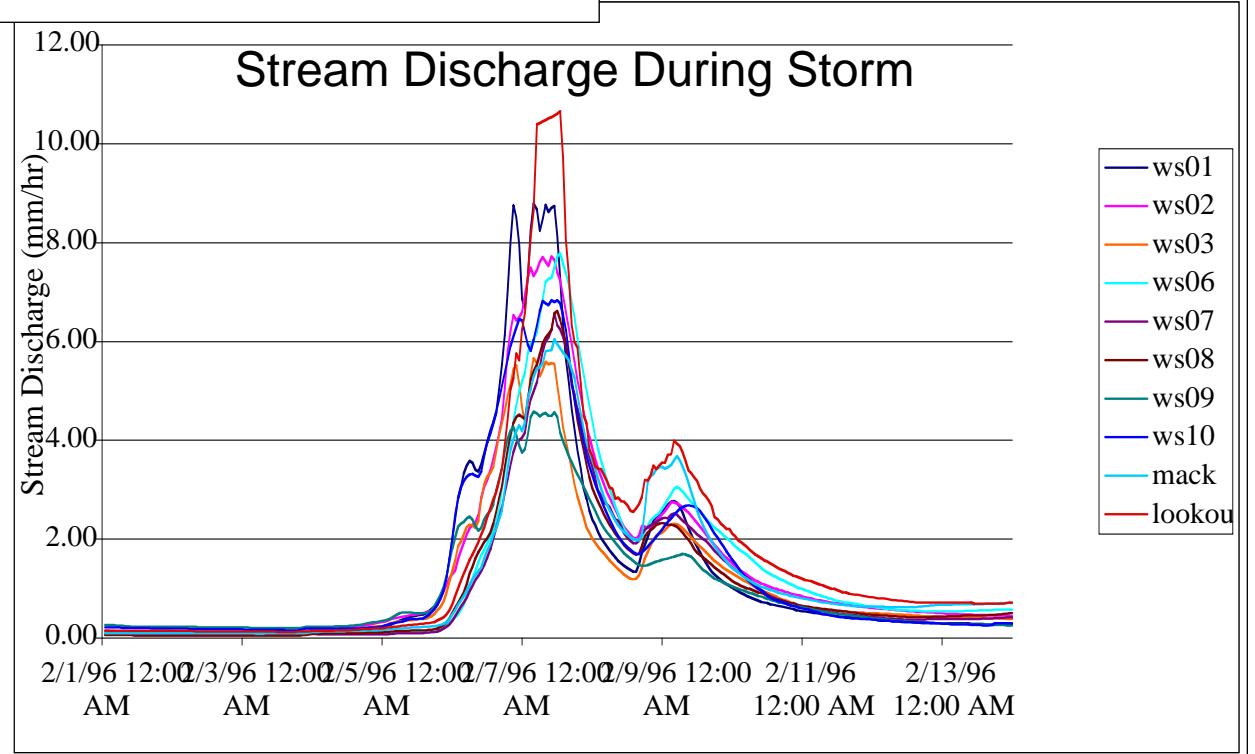
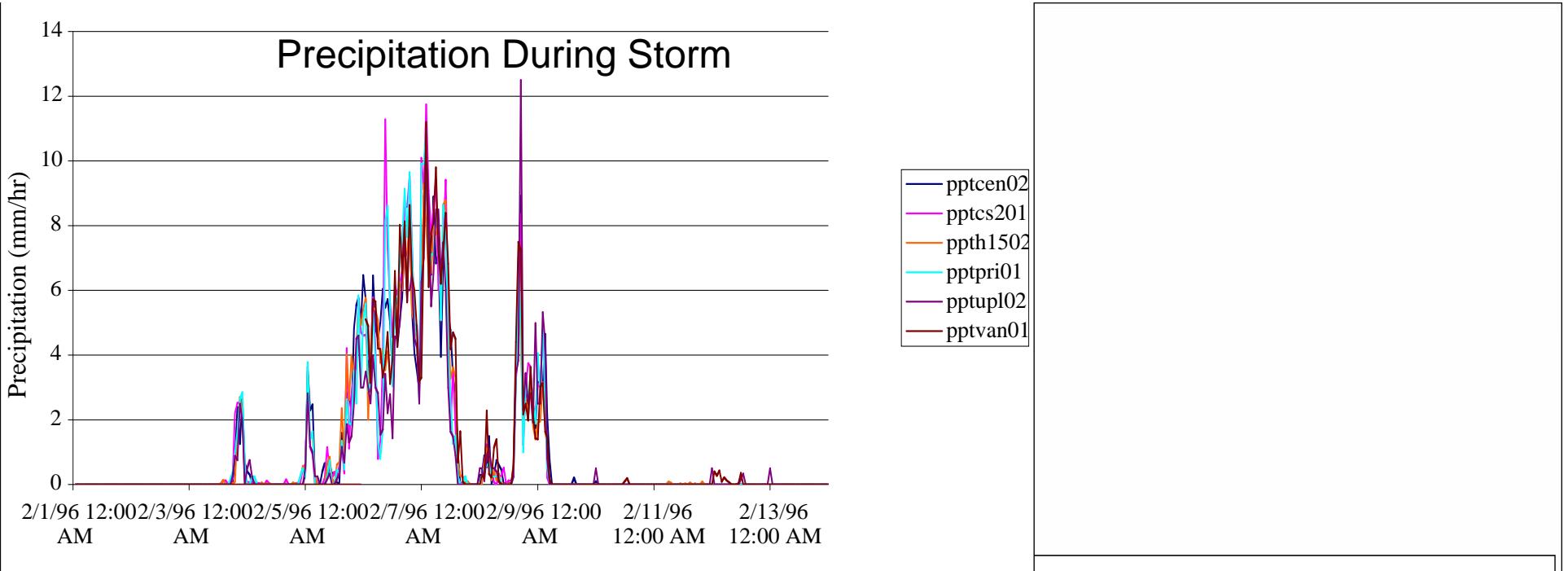


Source: Christopherson, Robert.
Elemental Geosystems. Upper
Saddle River: Pearson Education,
2004.

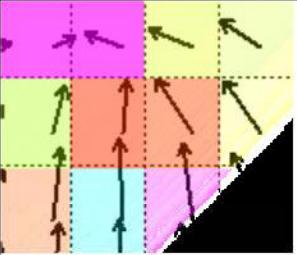


Event Used For Visualization

- Willamette Valley Flood
- February 1-14, 1996
- Rain-on-snow flood
- Part of a larger series of floods in the Pacific Northwest



Source: Perkins, R.M. and J.A. Jones. In press.
Climate variability, snow and physiographic
controls on storm hydrographs in small forested
basins, western Cascades, Oregon. *Hydrological
Processes.*

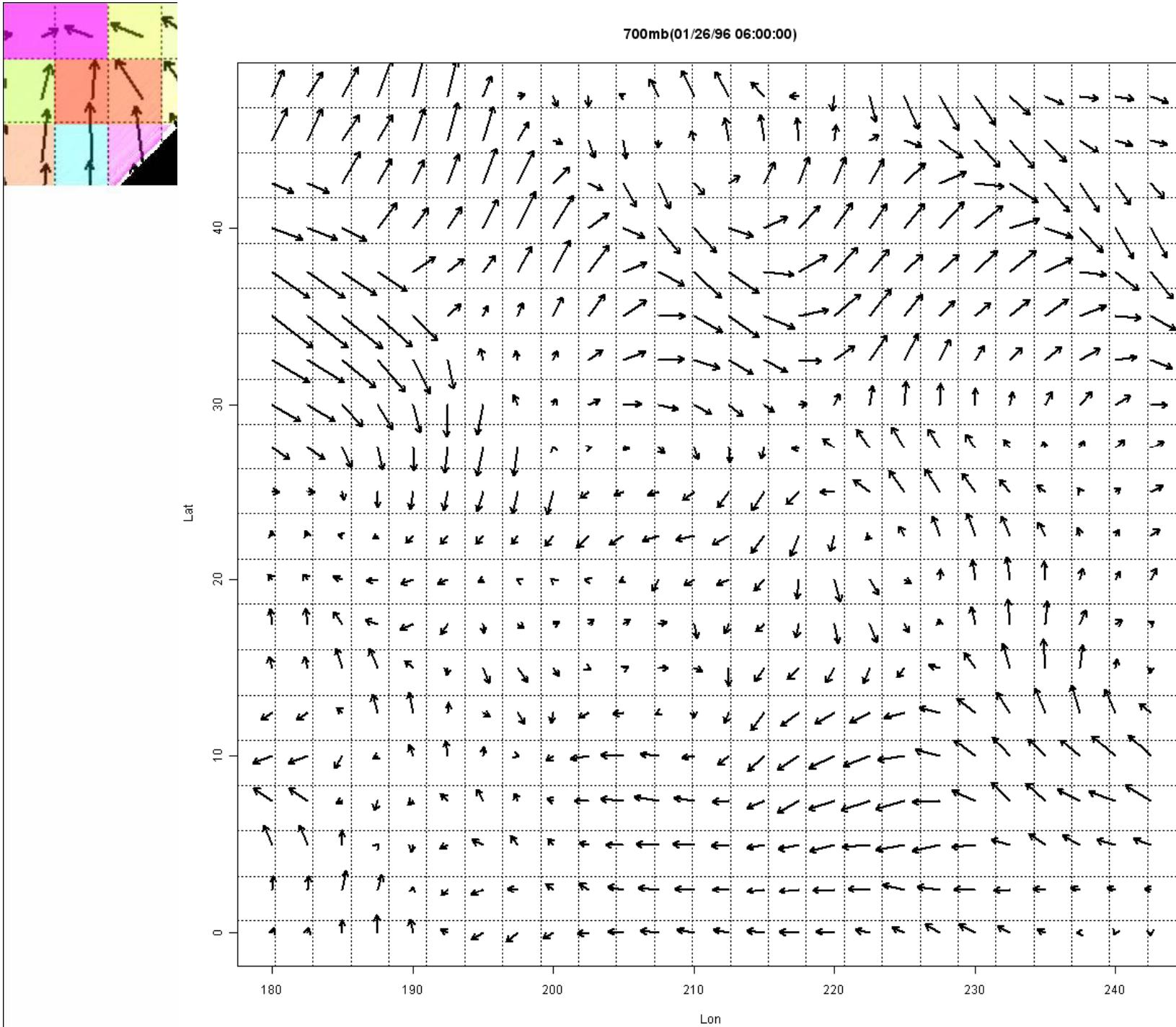


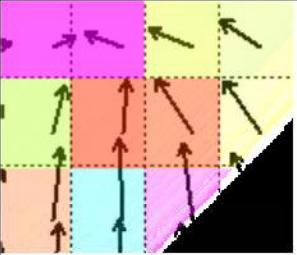
Data used for Visualization

- NCEP Reanalysis 2 Dataset
- 6 hour intervals giving latitudinal and longitudinal winds at various pressure levels
- Resolution: Every 2.5 degrees
- Bottom left: 0°N , 180°E
Top right: 47.5°N , 242.5°E

Pressure (hPa)	Altitude (m)
1,000	0 (surface)
700	3,000
400	7,200
100	16,200

<http://www.cdc.noaa.gov/data/gridded/data.ncep.reanalysis2.pressure.html>



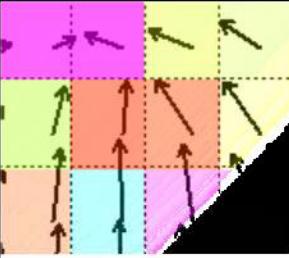


Computing Tensor Field

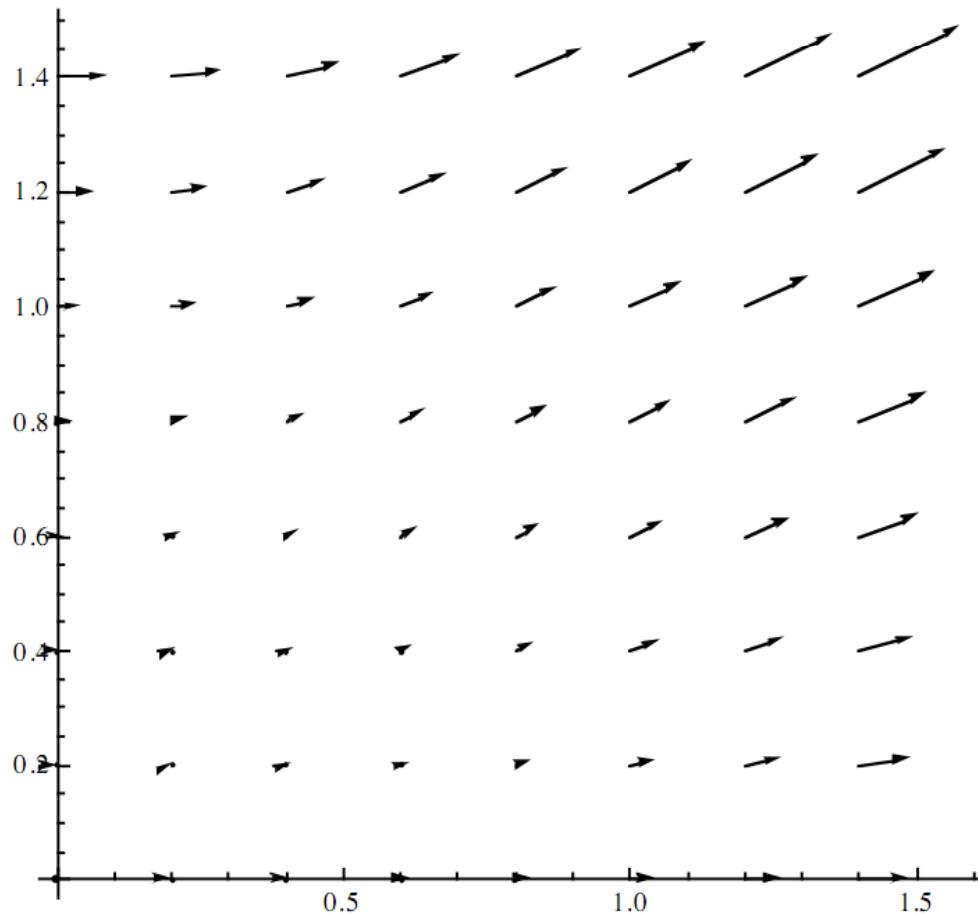
- Gradient of velocity vector field

$$v(x,y) = \begin{pmatrix} v_1(x,y) \\ v_2(x,y) \end{pmatrix}$$

$$T(x,y) = \begin{pmatrix} \frac{\partial}{\partial x} v_1(x,y) & \frac{\partial}{\partial y} v_1(x,y) \\ \frac{\partial}{\partial x} v_2(x,y) & \frac{\partial}{\partial y} v_2(x,y) \end{pmatrix}$$

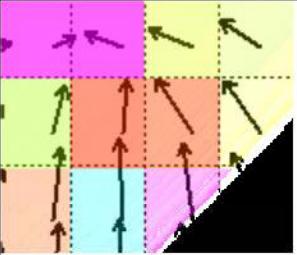


Example of Tensor Derivation



$$v(x,y) = \begin{pmatrix} x^2 + y^2 \\ xy \end{pmatrix}$$

$$T(x,y) = \begin{pmatrix} 2x & 2y \\ y & x \end{pmatrix}$$



Tensor Decomposition

$$T = \begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix} = \gamma_d \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} + \gamma_r \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix} + \gamma_s \begin{pmatrix} \cos \theta & \sin \theta \\ \sin \theta & -\cos \theta \end{pmatrix}$$

$$\gamma_d = \frac{T_{11} + T_{22}}{2}$$

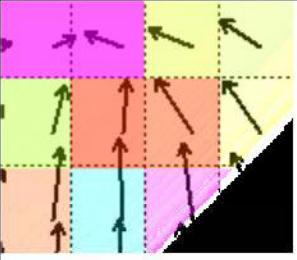
Isotropic Scaling

$$\gamma_r = \frac{T_{21} - T_{12}}{2}$$

Rotation

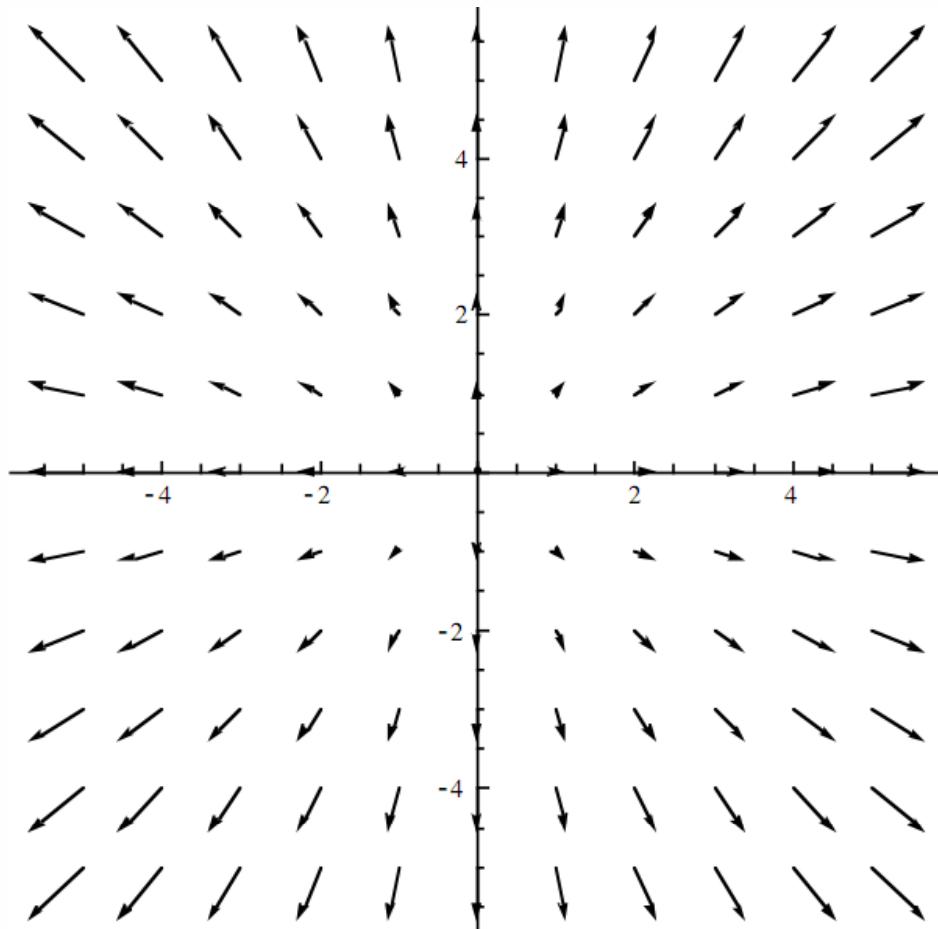
$$\gamma_s = \frac{\sqrt{(T_{11} - T_{22})^2 + (T_{12} + T_{21})^2}}{2}$$

Anisotropic
Stretching



Isotropic Scaling

Expansion or contraction at a given point

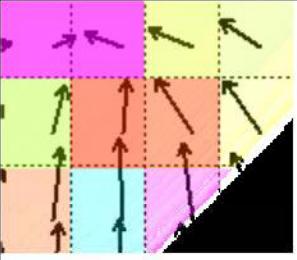


$$v(x,y) = \begin{pmatrix} x \\ y \end{pmatrix}$$
$$T(x,y) = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

$$\gamma_d = 1$$

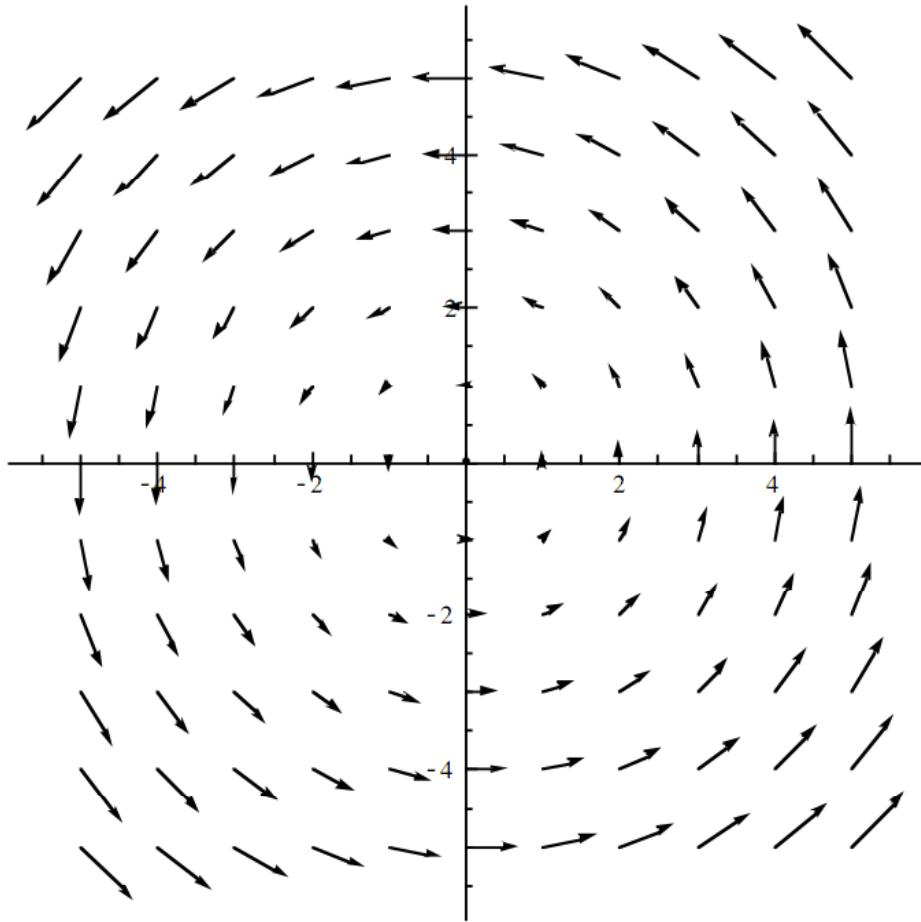
$$\gamma_r = 0$$

$$\gamma_s = 0$$



Rotation

Clockwise or counter-clockwise

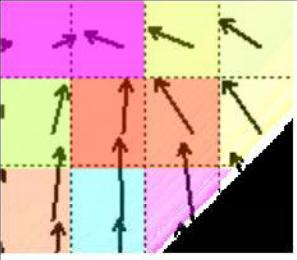


$$v(x,y) = \begin{pmatrix} -y \\ x \end{pmatrix}$$
$$T(x,y) = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

$$\gamma_d = 0$$

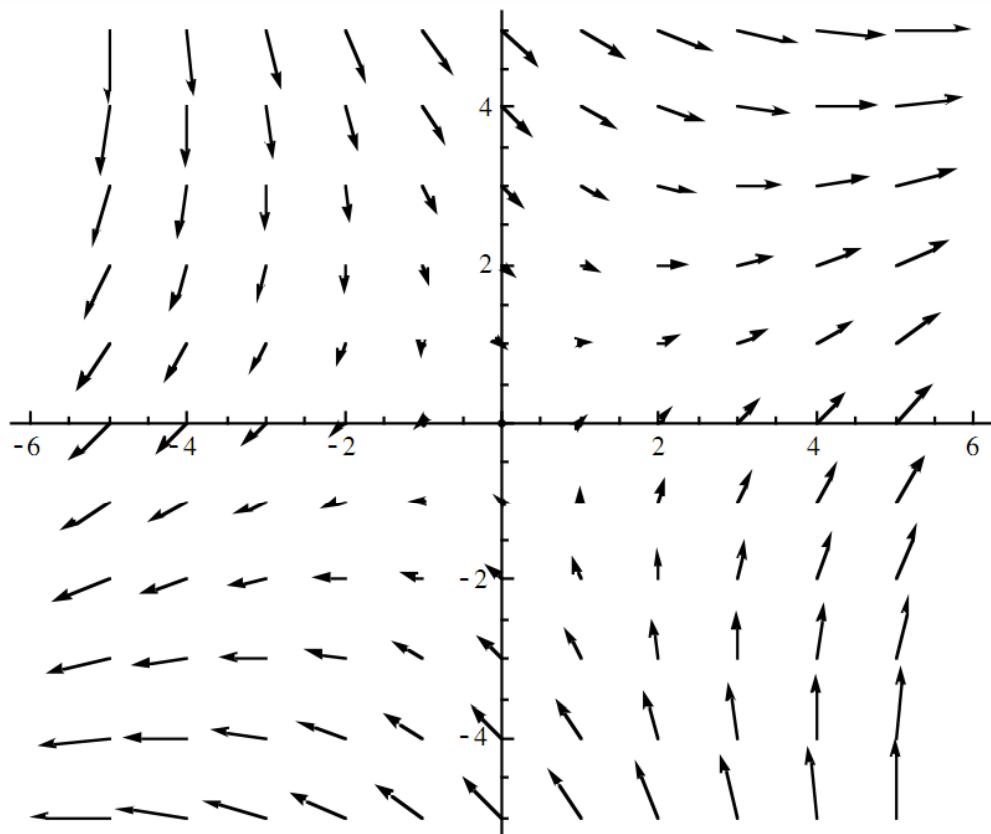
$$\gamma_r = 1$$

$$\gamma_s = 0$$



Anisotropic Stretching

Uneven expansion or compression resulting in stretching at a given point



$$v(x,y) = \begin{pmatrix} x + y \\ x - y \end{pmatrix}$$

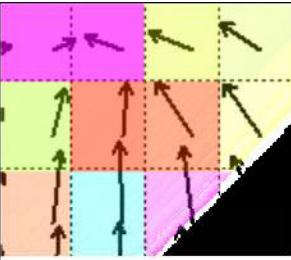
$$T(x,y) = \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$

$$\gamma_d = 0$$

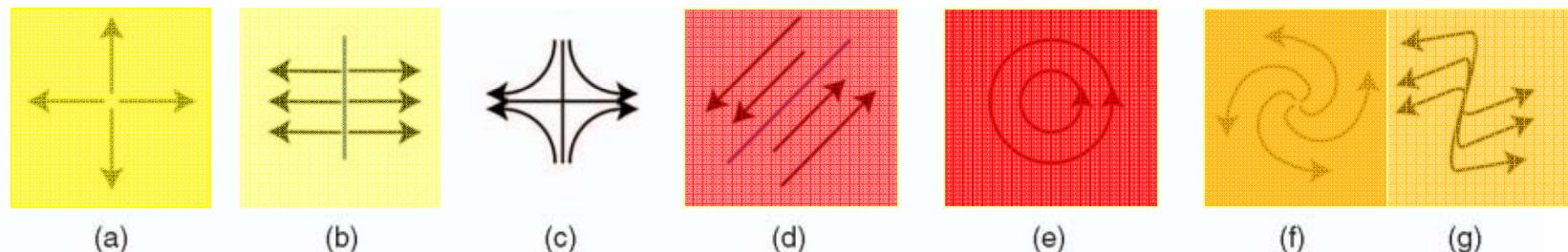
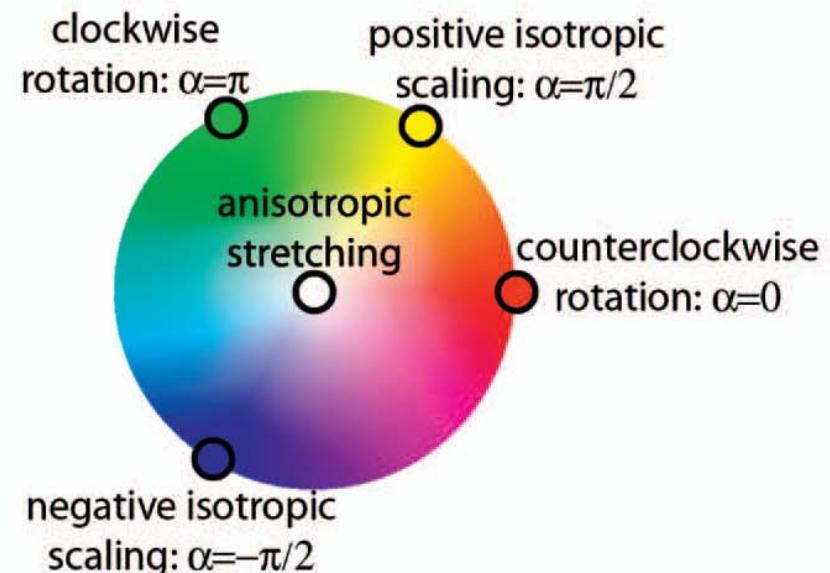
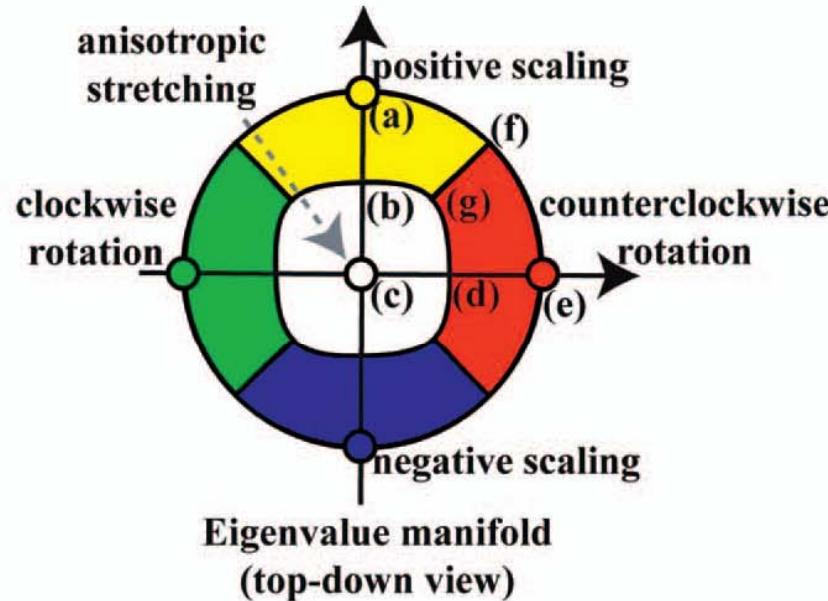
$$\gamma_r = 0$$

$$\gamma_s = \sqrt{2}$$

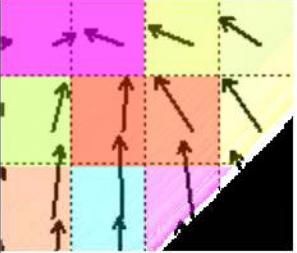
$$\theta = 45^\circ$$



Coloring



Zhang, E., H. Yeh, Z. Lin and R.S. Laramee. Asymmetric Tensor Analysis for Flow. 2009.
IEEE Transactions on Visualization and Computer Graphics 15, 1 2009.



Color Application



Cyclone (NH)



Cyclone (SH)



Anti-cyclone (NH)

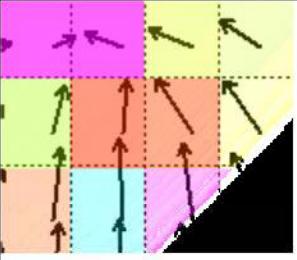


Anti-cyclone (SH)



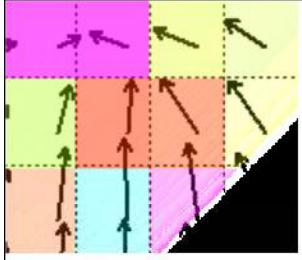
Visualization Software – Velocity Plots

- R Programming Language
- Read in NCEP data, plotted velocity vectors for each Lat, Long, 6 hour interval
- Generated a set of plots for each pressure level
- Added cities to identify location of storms



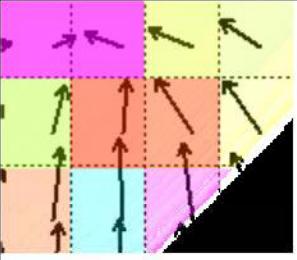
Visualization Software – Programming Components

- OpenGL used to display velocity vector plots and visualize tensors
- C++ used to read in NCEP velocity data and compute tensor fields
 - Also used to interface with OpenGL
- GLUI provides a user interface to manipulate visualization



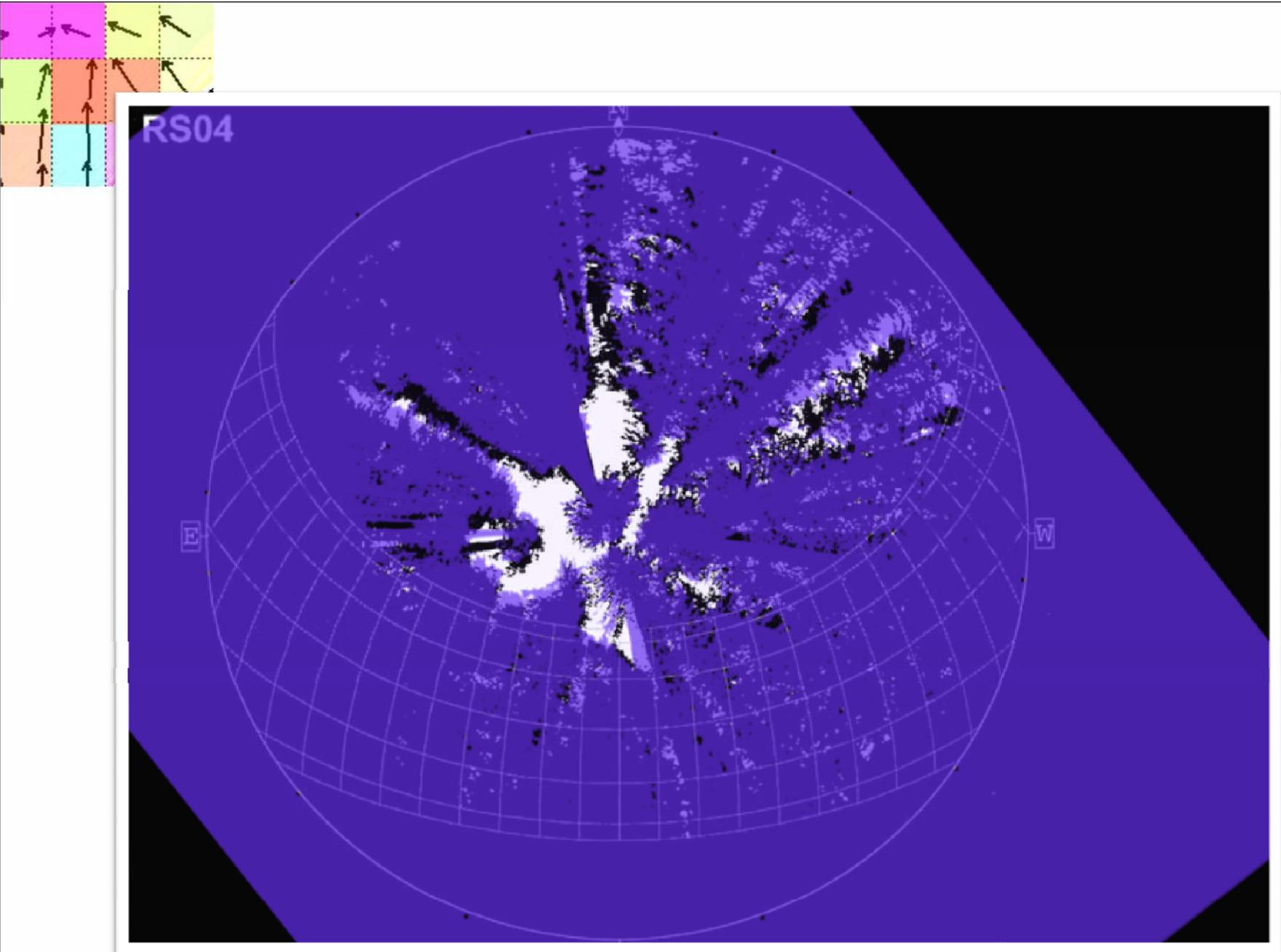
Visualization Software – Decomposition Coloring

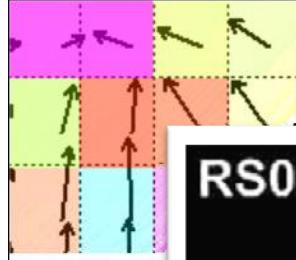
- Computed decompositions from tensor field
- OpenGL used to overlay coloring scheme on velocity plots
- Allows us to see spatial distortions in addition to wind speed and direction



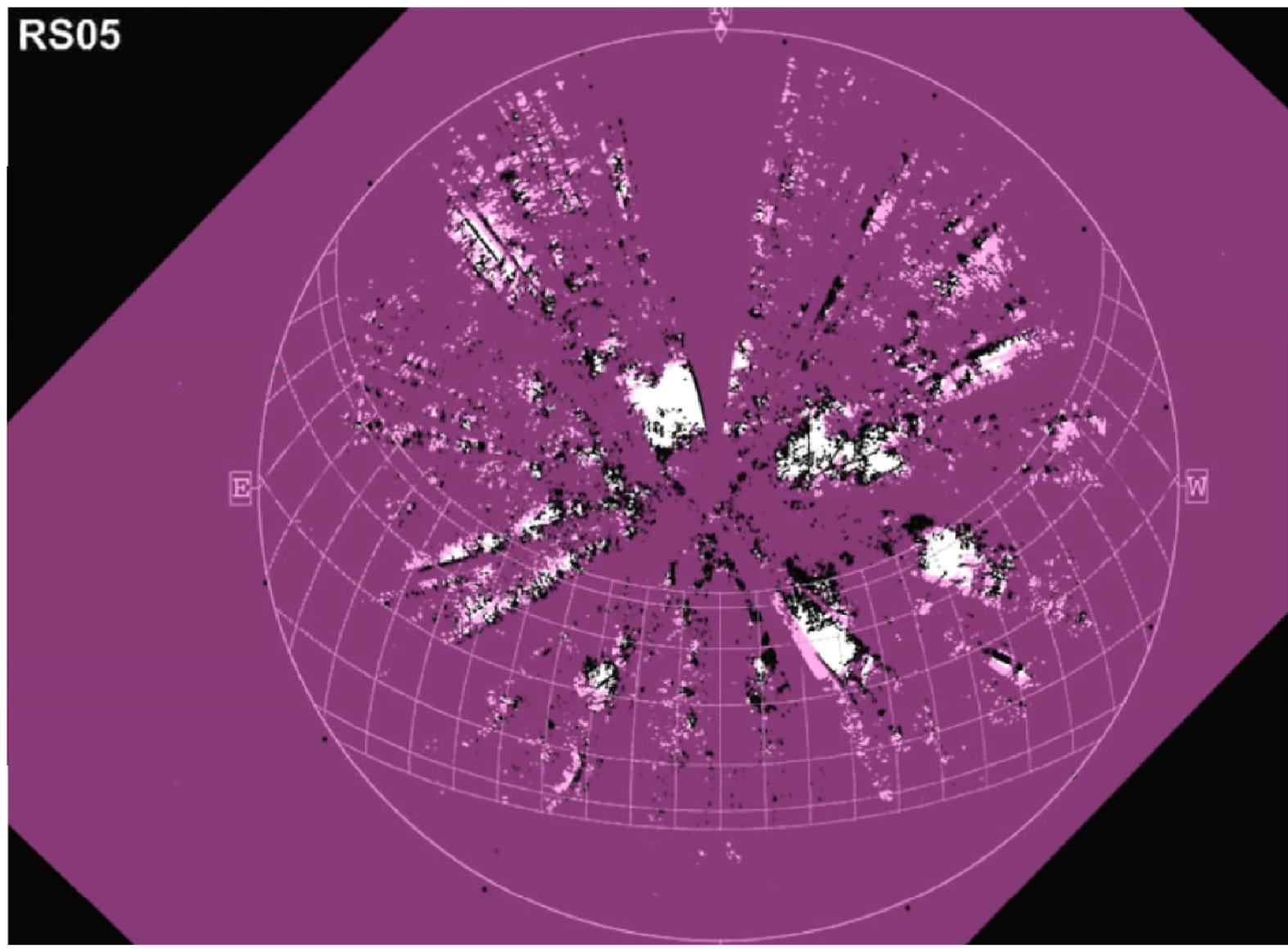
Moving Frame Transforms

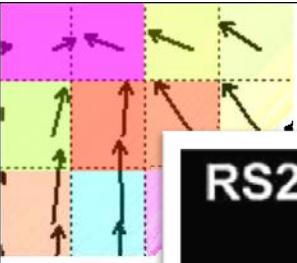
- Derive a set of transformation to rewrite positions, velocities, and tensor fields as observed in different frames of reference
- Spatial distortion coefficients in tensor decomposition remain the same



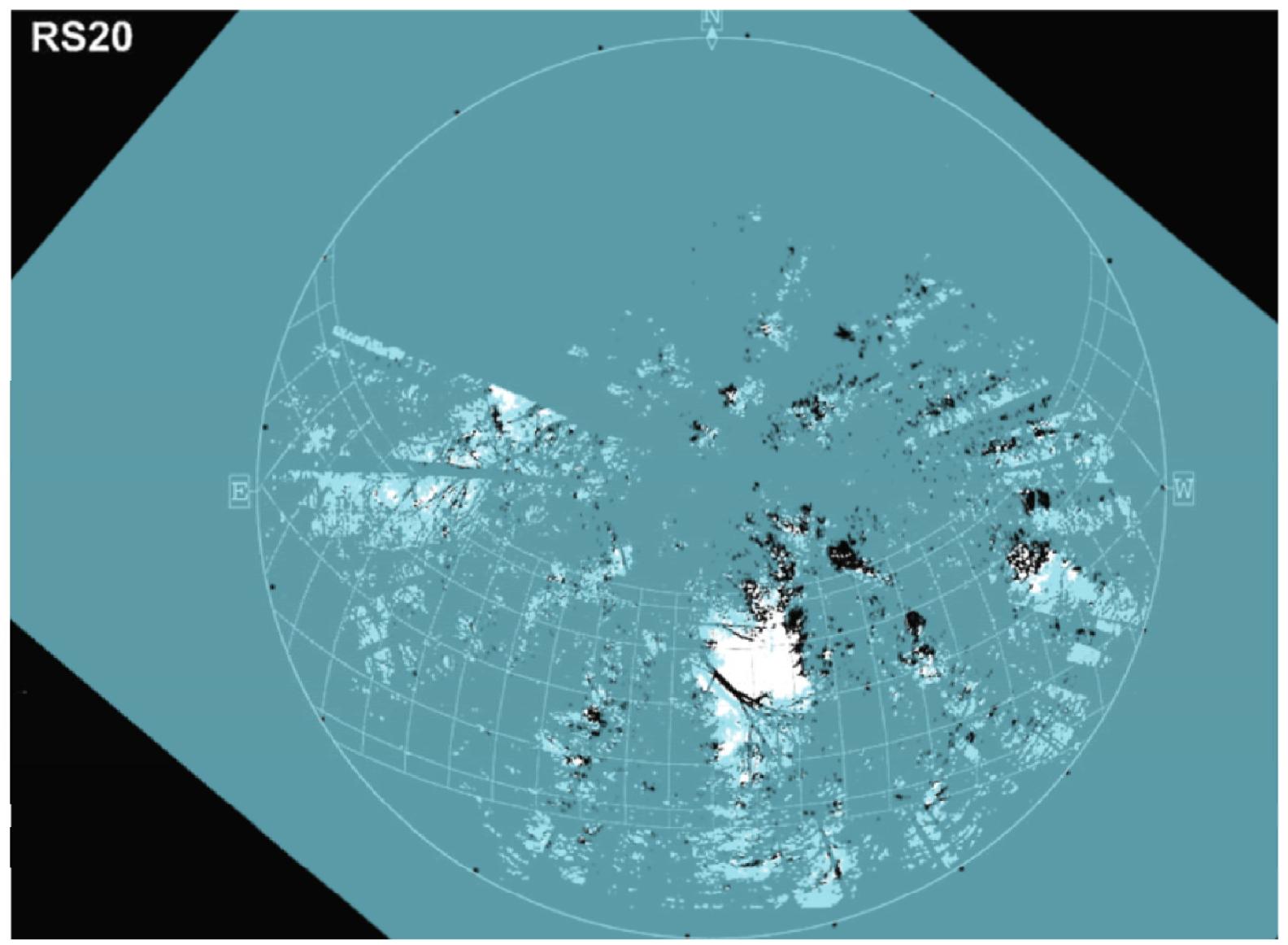


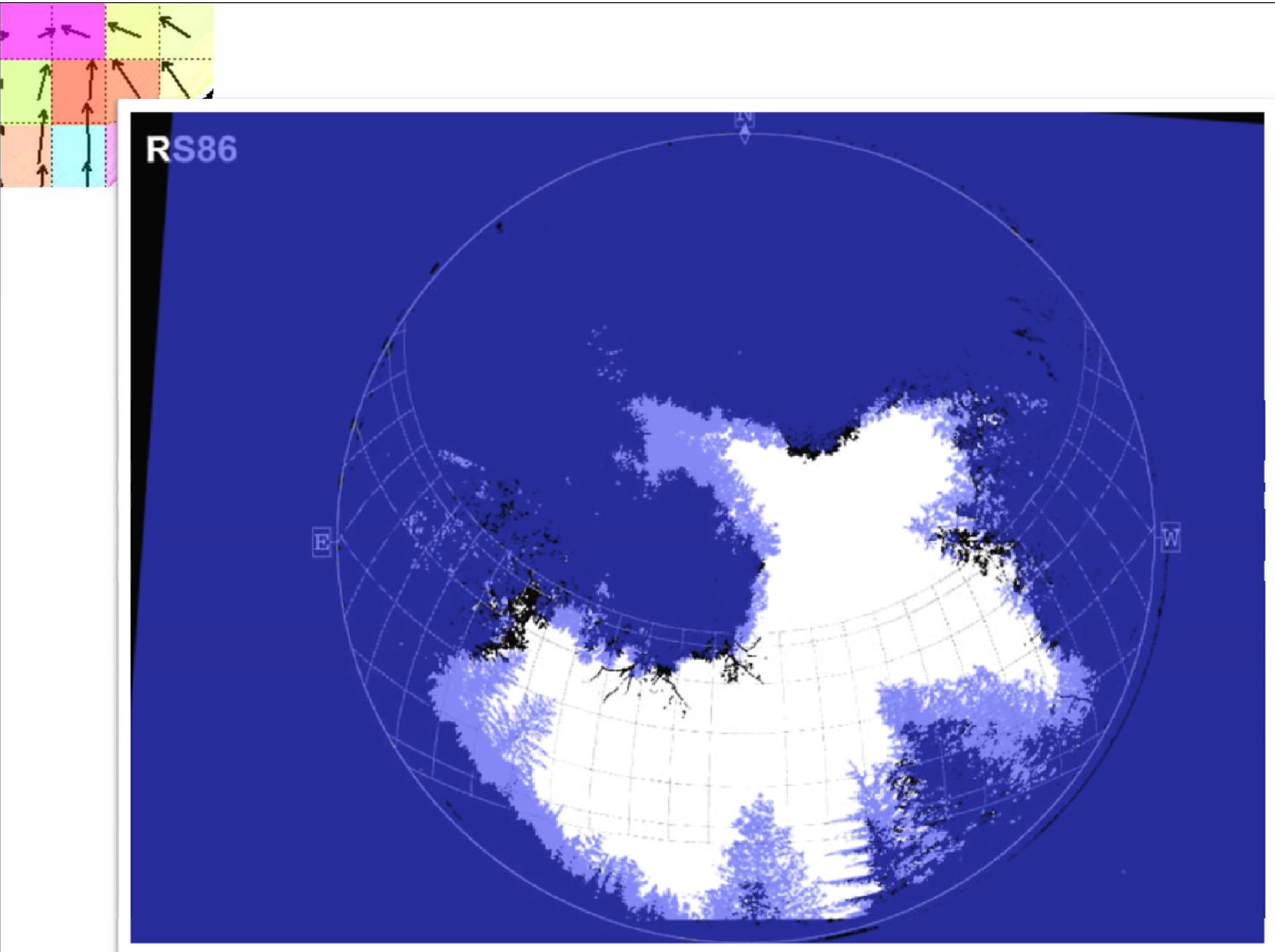
RS05

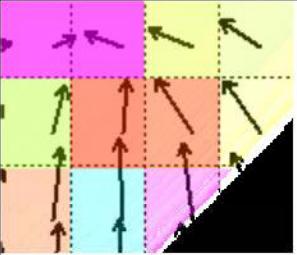




RS20

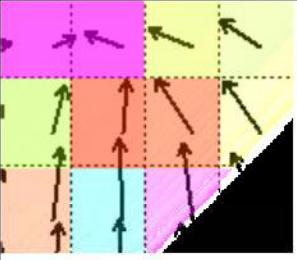






Canopy Change

Reference Stand	% Canopy Openness 2009	% Canopy Openness 2001
2	5.52	6.88
4	9.82	7.01
5	9.14	6.27
10	12.14	5.24
12	6.16	4.78
20	4.49	9.86
26	6.91	9.2
38	11.56	13.88
86	28.88	38.25
89	11.61	8.78



Conclusions

- Visualization useful to recognize characteristics of air masses and atmospheric circulation
- Visualization did not perfectly correlate with observed data at the Andrews