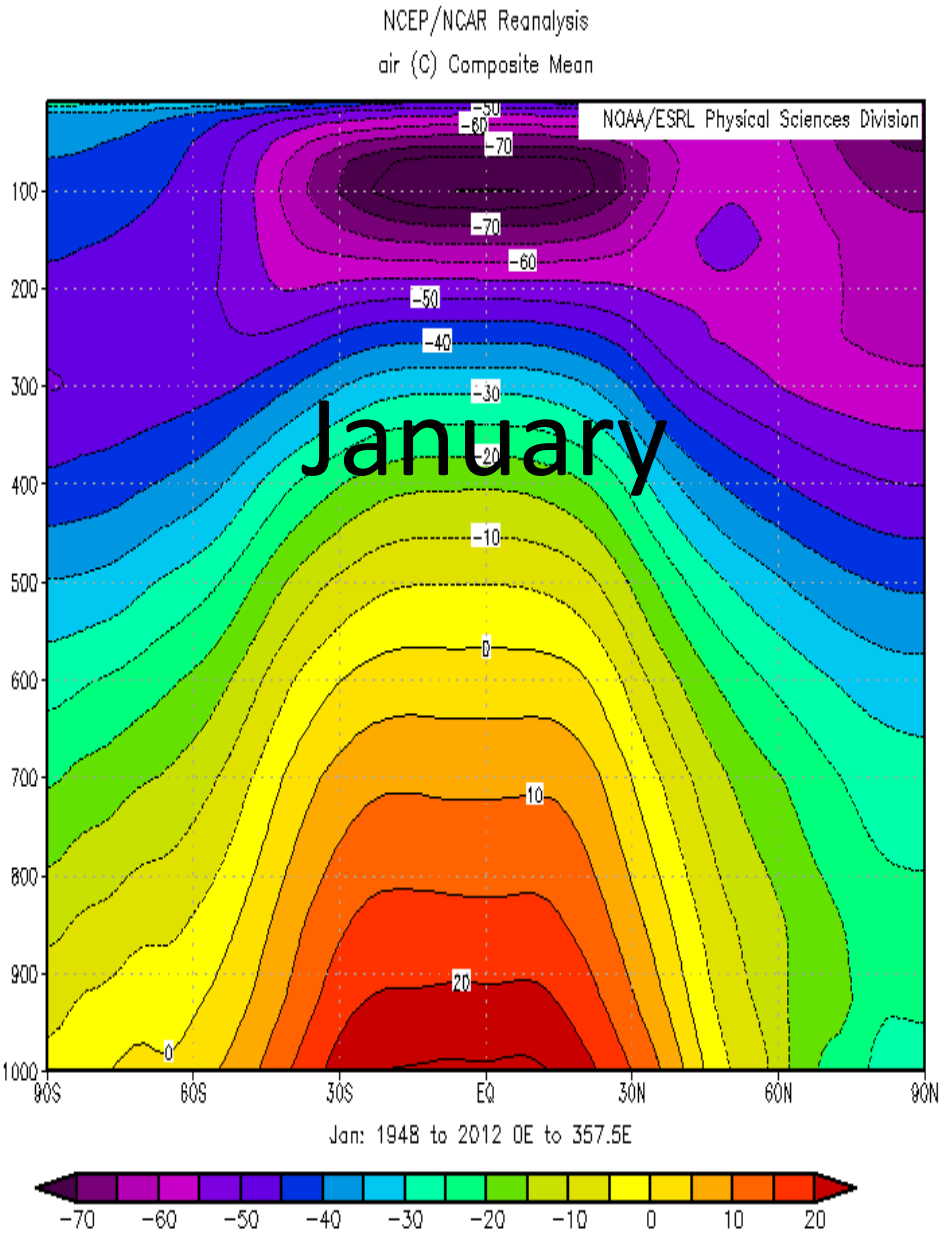
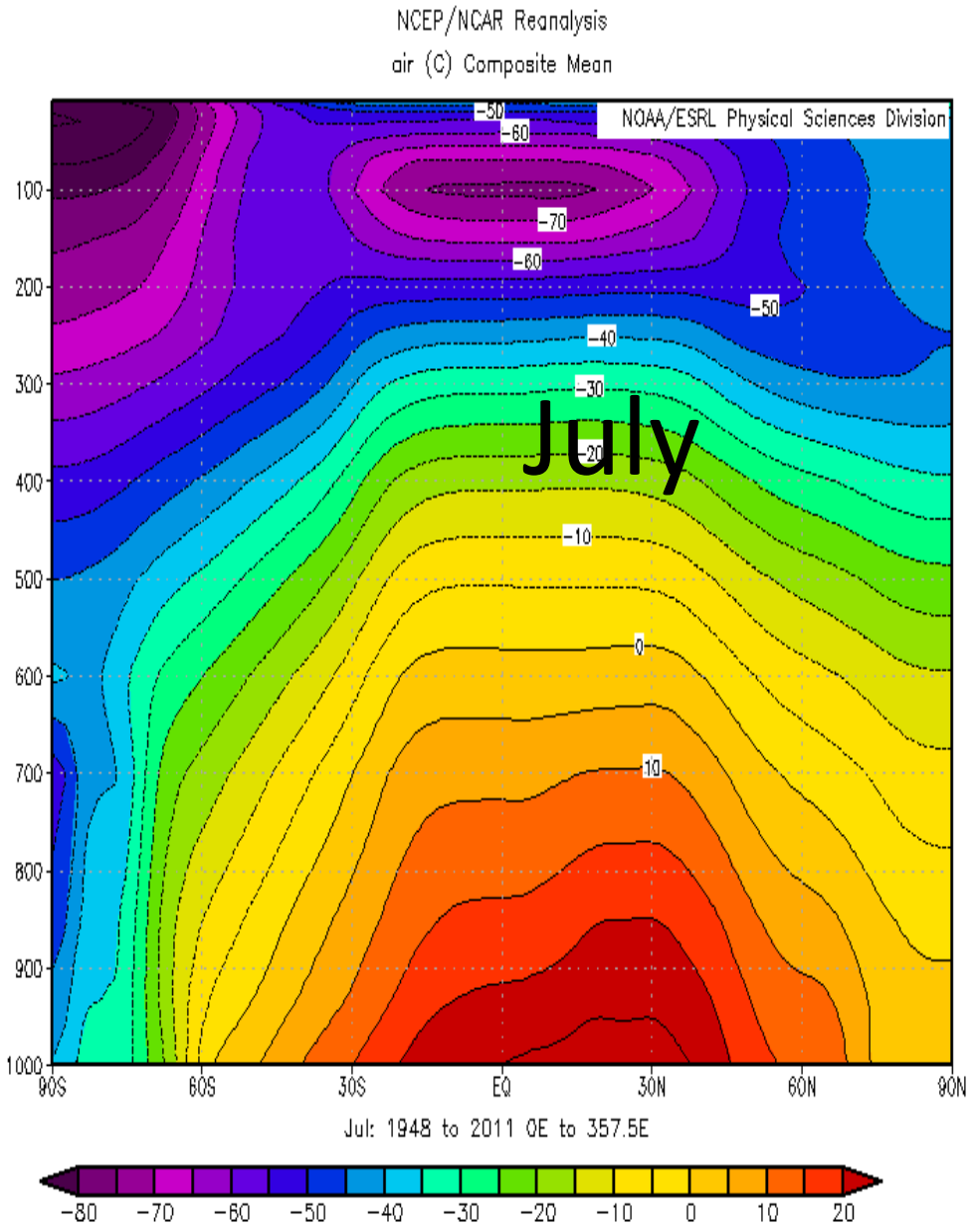
General Circulation – Hadley Cells

Drew Whisenant

Atmospheric Data

Zonally Averaged Temperature

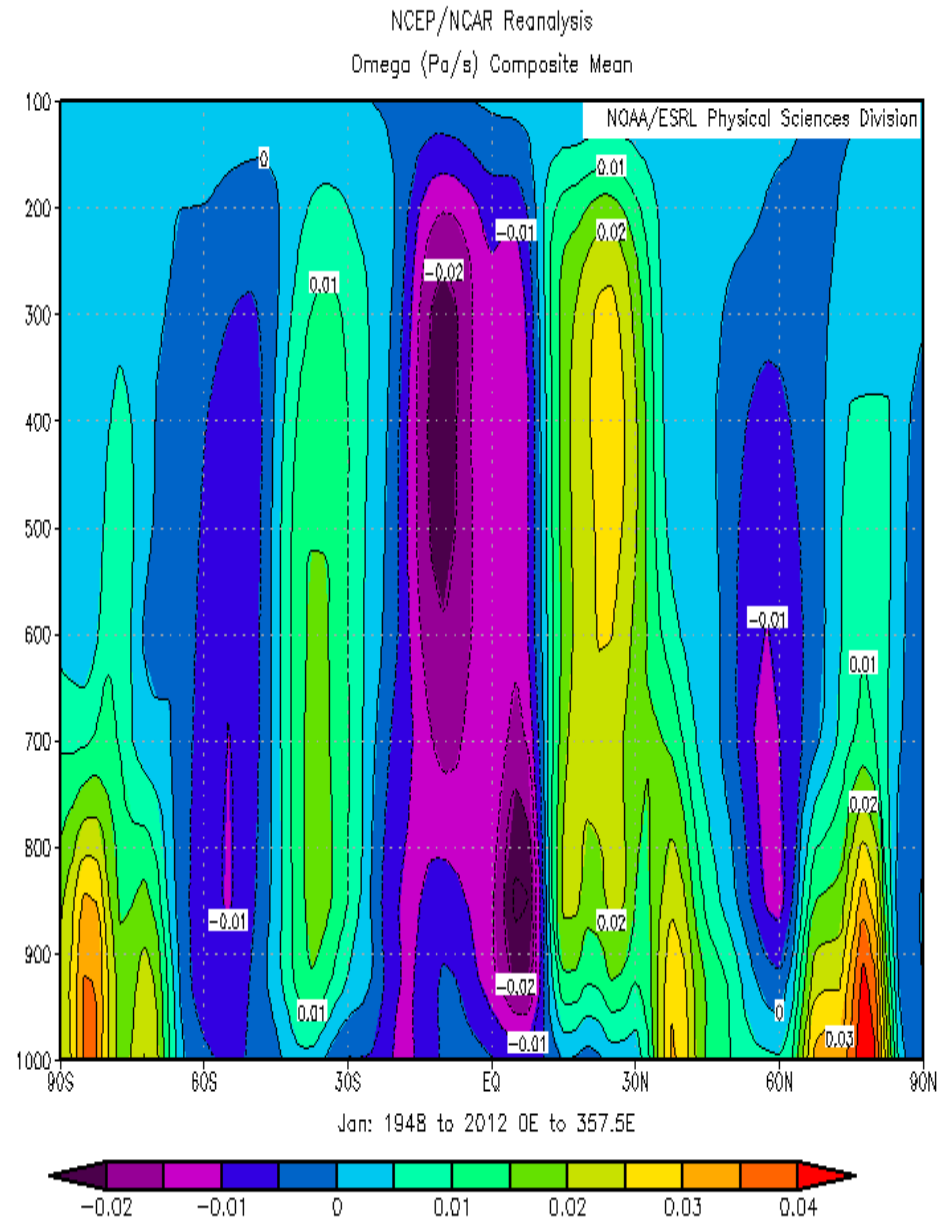


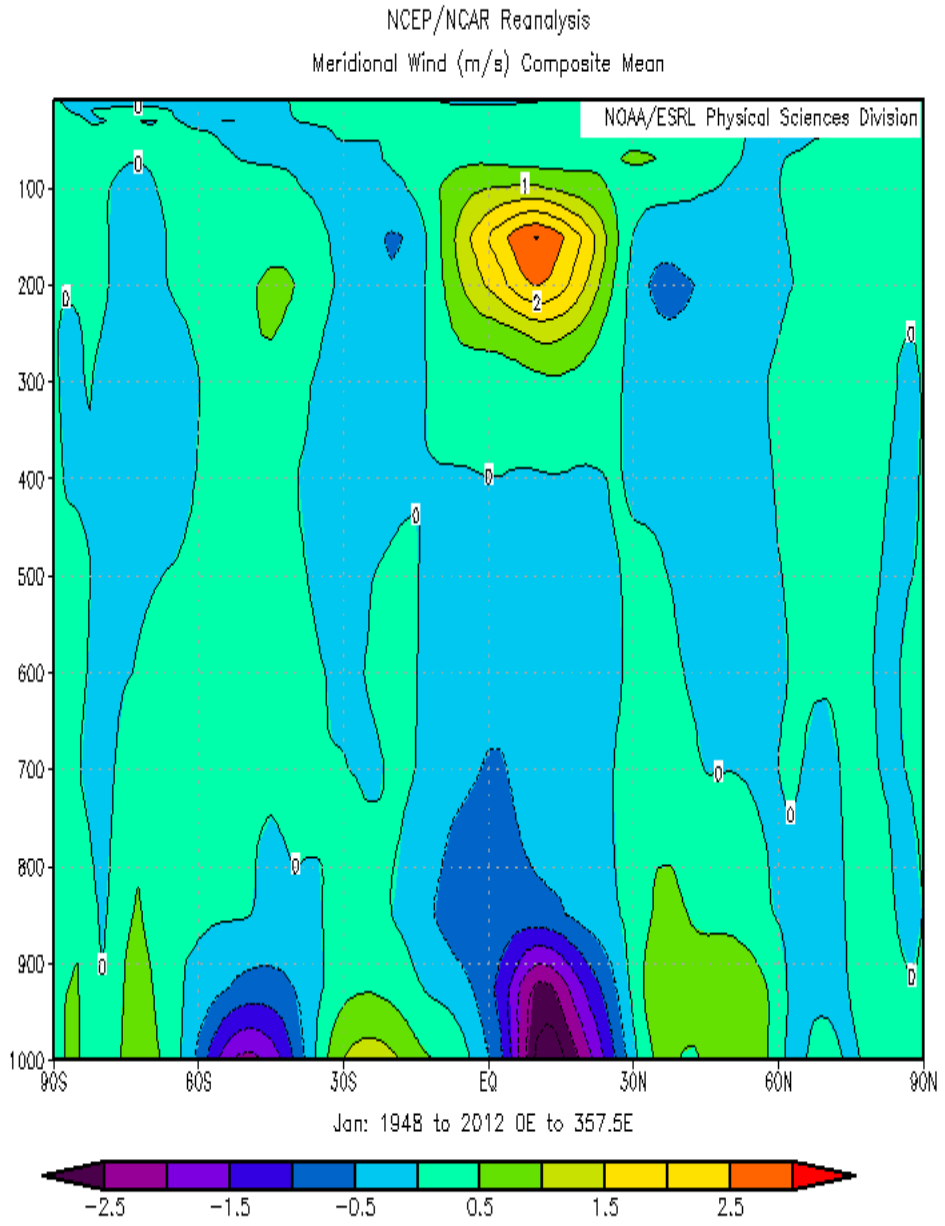


Zonally Averaged Temperature

- Recall – Fronts
  - Cold, dense air mass over the poles
    - Similar situation at equator
    - Warm, less dense air
    - Shifted South in January; North in July
  - Thermal Gradients
    - Also present for the Hadley cell
    - Greatest between 30 and 60 degrees North or South

January


NCEP/NCAR Reanalysis
Omega (Pa/s) Composite Mean
NOAA/ESRL Physical Sciences Division
100
200
300
400
500
600
700
800
900
1000
90S
60S
30S
EQ
30N
60N
90N
Jan: 1948 to 2012 0E to 357.5E
-0.02
-0.01
0
0.01
0.02
0.03
0.04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Meridional Wind (m/s) Composite Mean
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100
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800
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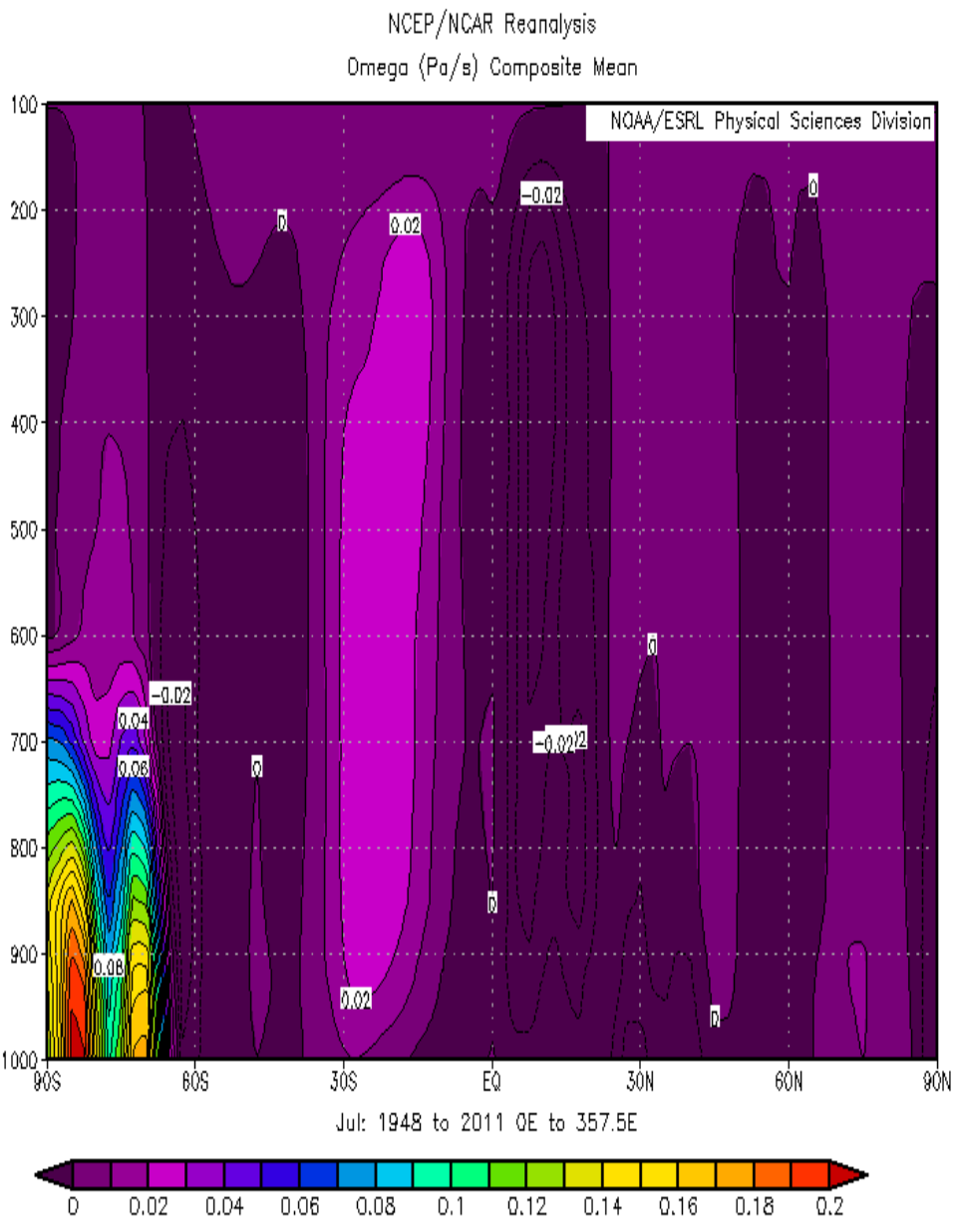
1000
90S
60S
30S
EQ
30N
60N
90N
Jan: 1948 to 2012 0E to 357.5E
-2.5
-1.5
-0.5
0.5
1.5
2.5

January

- Vertical Velocities
  - Positive near the equator (rising)
  - Negative just outside equatorial region (falling)
  - Positive again outside of the negative region (rising)
  - Convection phenomenon
- Meridional Wind
  - Illustrative of convection observed from the vertical velocities (omega) data

July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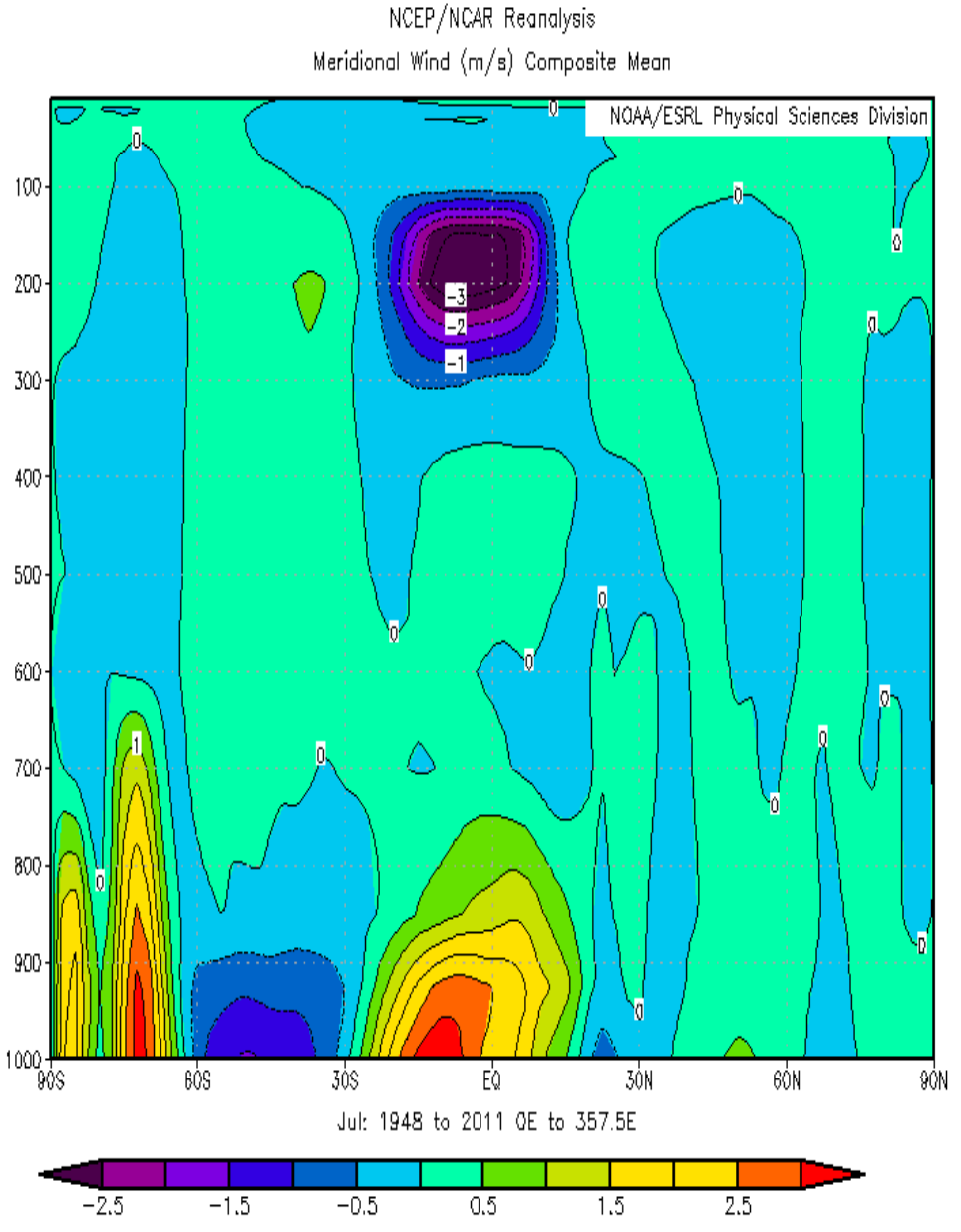
90N
Jul: 1948 to 2011 0E to 357.5E
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2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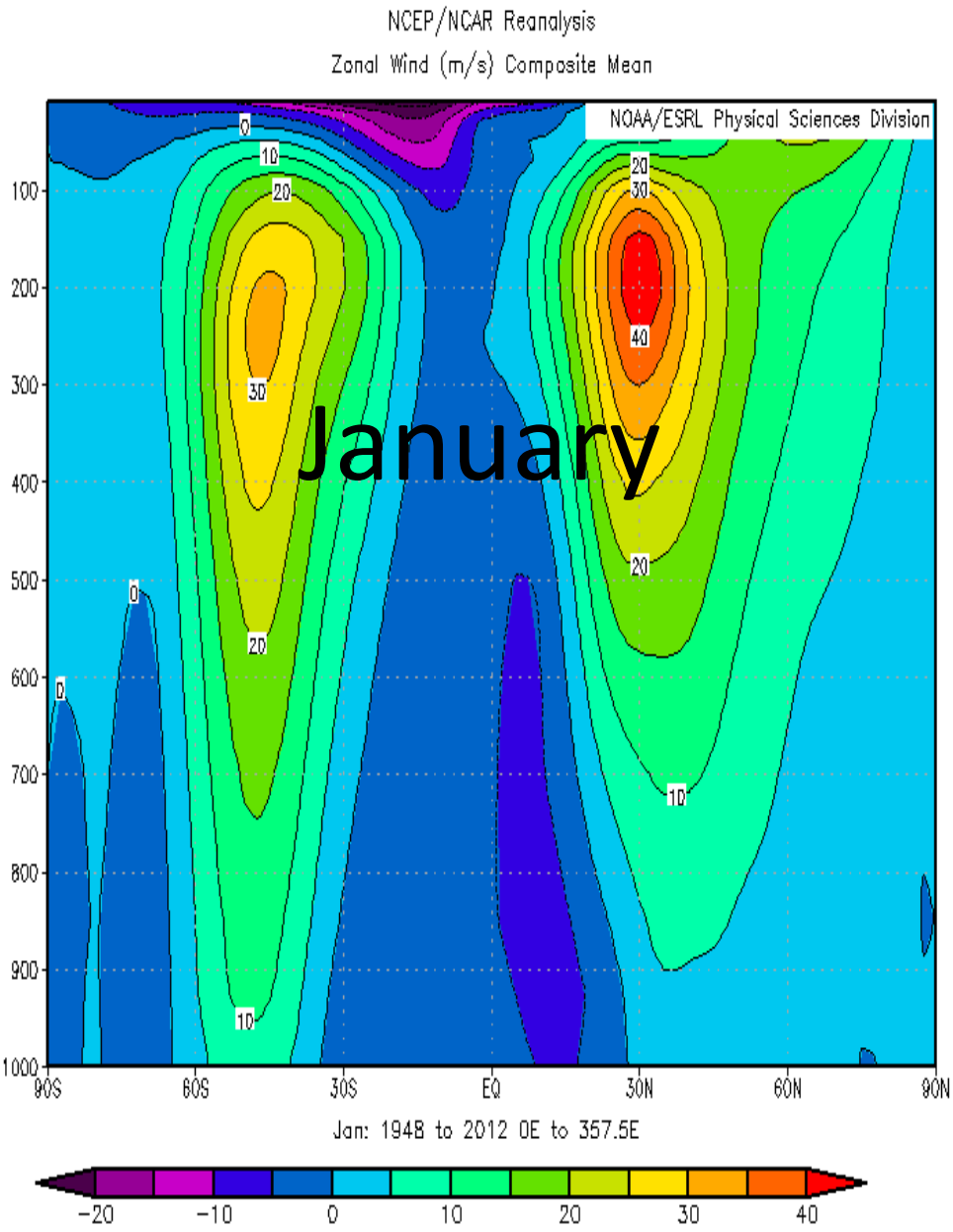
−1.5
−0.5
0.5
1.5
2.5

July

- Vertical Velocities
  - Similar to January data
  - Error in output; pressure range too great
- Meridional Wind
  - Similar to January Data

Zonal Wind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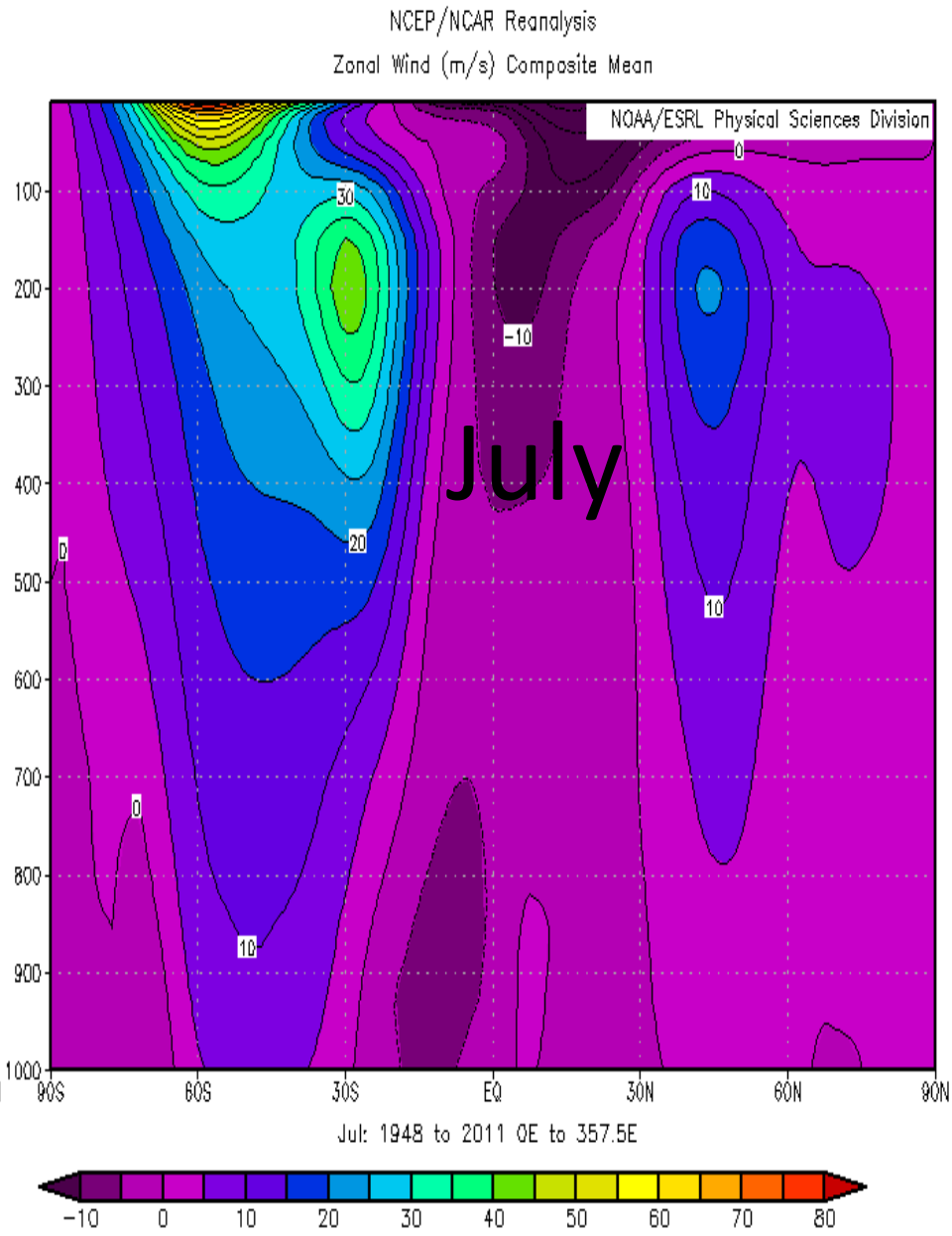
Jan: 1948 to 2012 0E to 357.5E
-20
-10
0
10
20
30
40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Zonal Wind (m/s) Composite Mean
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Jul: 1948 to 2011 0E to 357.5E
-10
0
10
20
30
40
50
60
70
80

Zonal Wind

- Velocity Data
  - Greatest velocities occur between 30 and 60 degrees North and South
  - Shifting results from seasonal variation between the two hemispheres
  - Greatest velocities correspond to the regions of sharpest gradient as in the case of the frontal study
  - Obeys thermal wind relationship

Thermal Wind

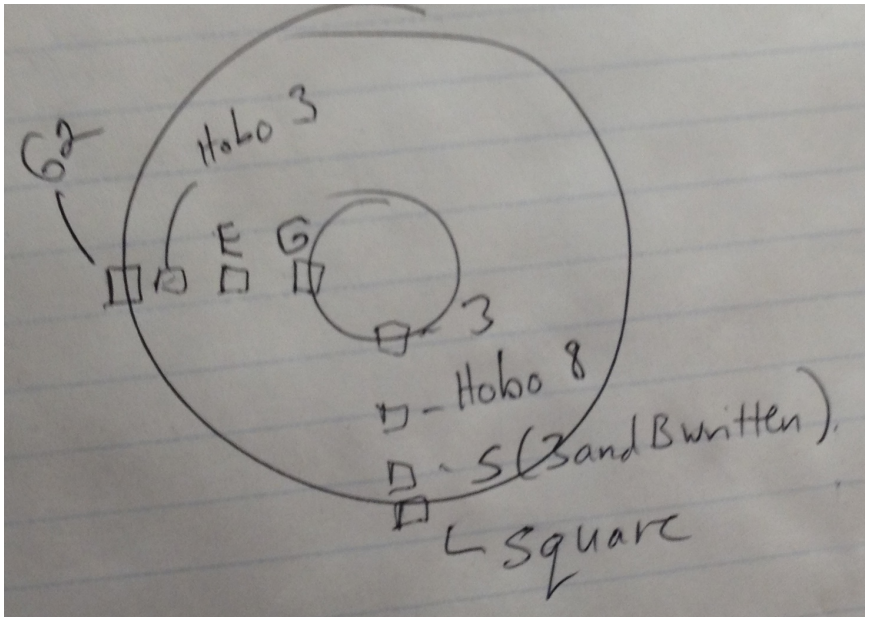
$$\frac{\partial u}{\partial p} = \frac{R}{fp}\left(\frac{\partial T}{\partial y}\right)_p$$

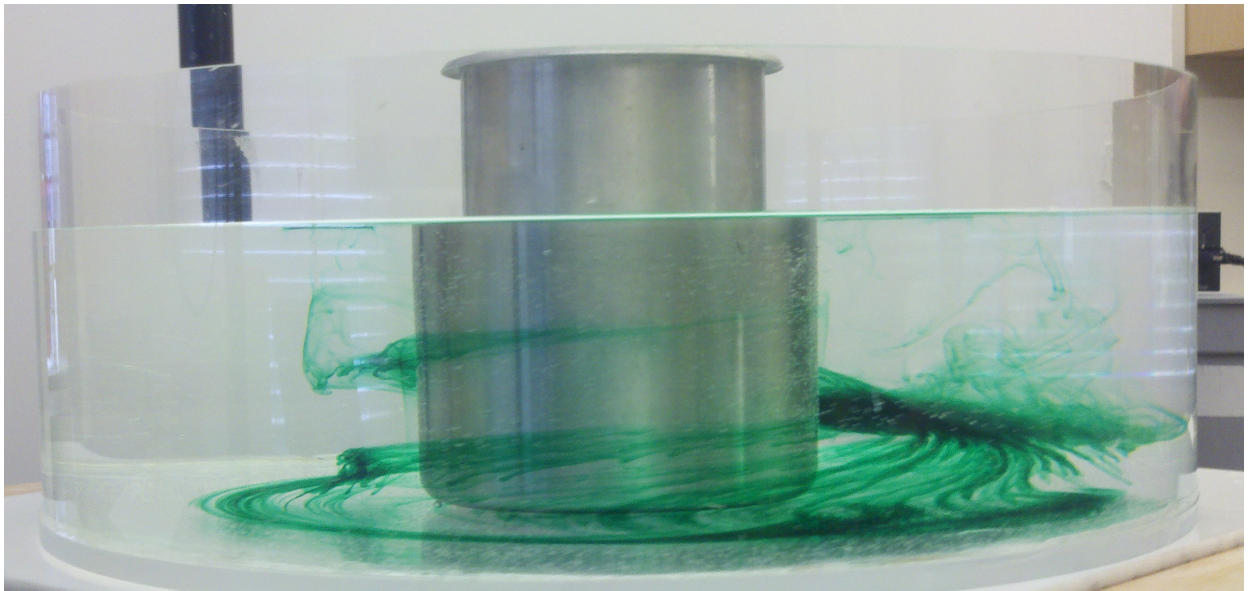
- R – Ideal Gas Constant
- u – zonal wind
- p – pressure
- T – temperature
- y – latitude
- f – Rotational factor

Experimental Data

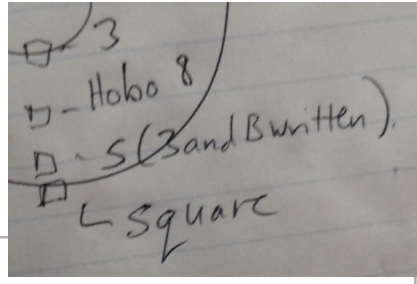
Laboratory Experiment

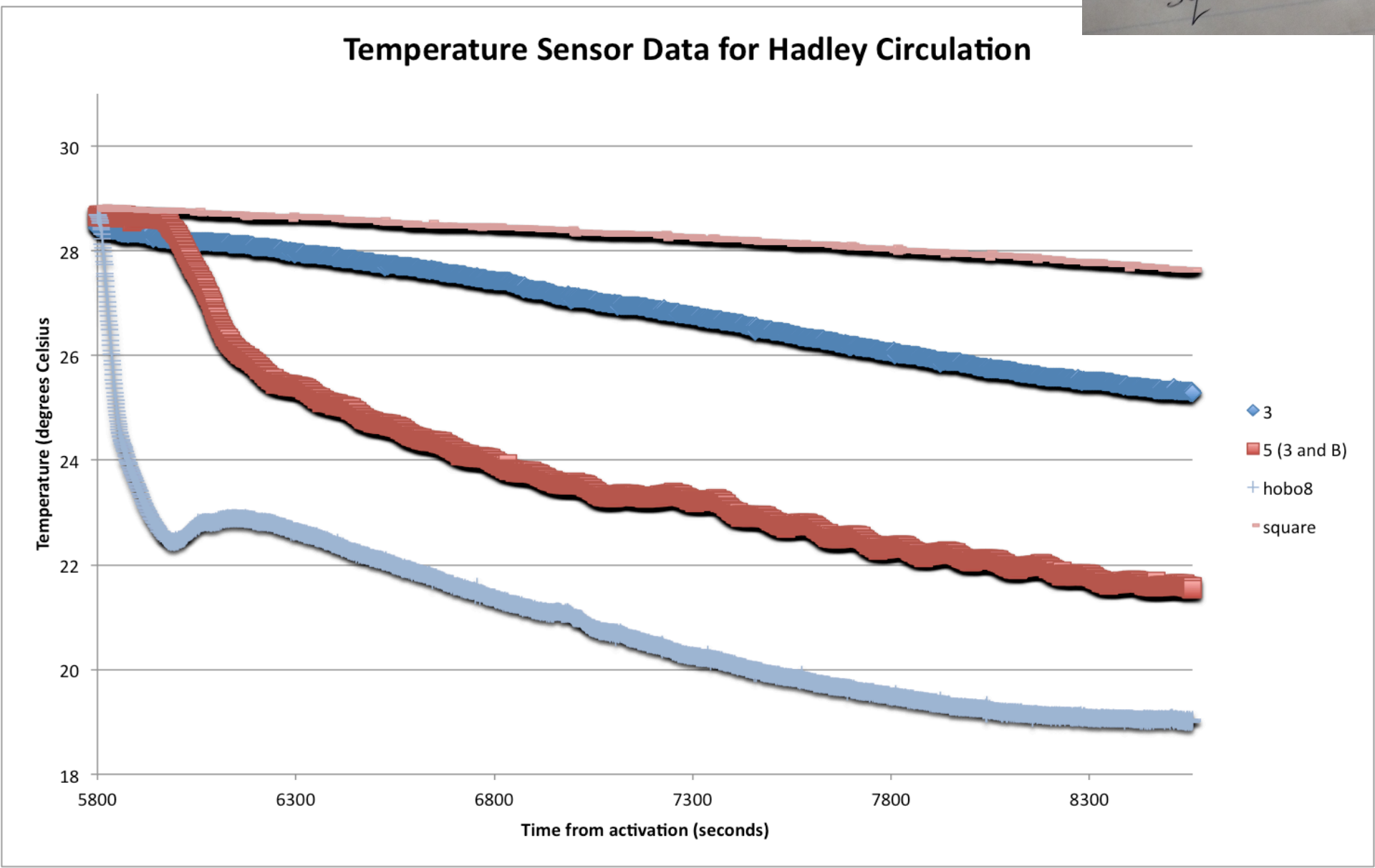
- Low rotation
  - Less than 1 rpm
- Two sets of sensors
  - Four each
  - Perpendicular
- Ice placed in canister





Temperature Data





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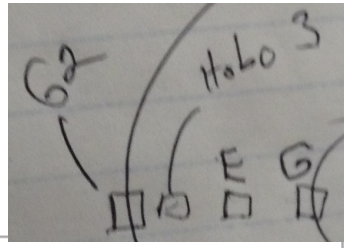
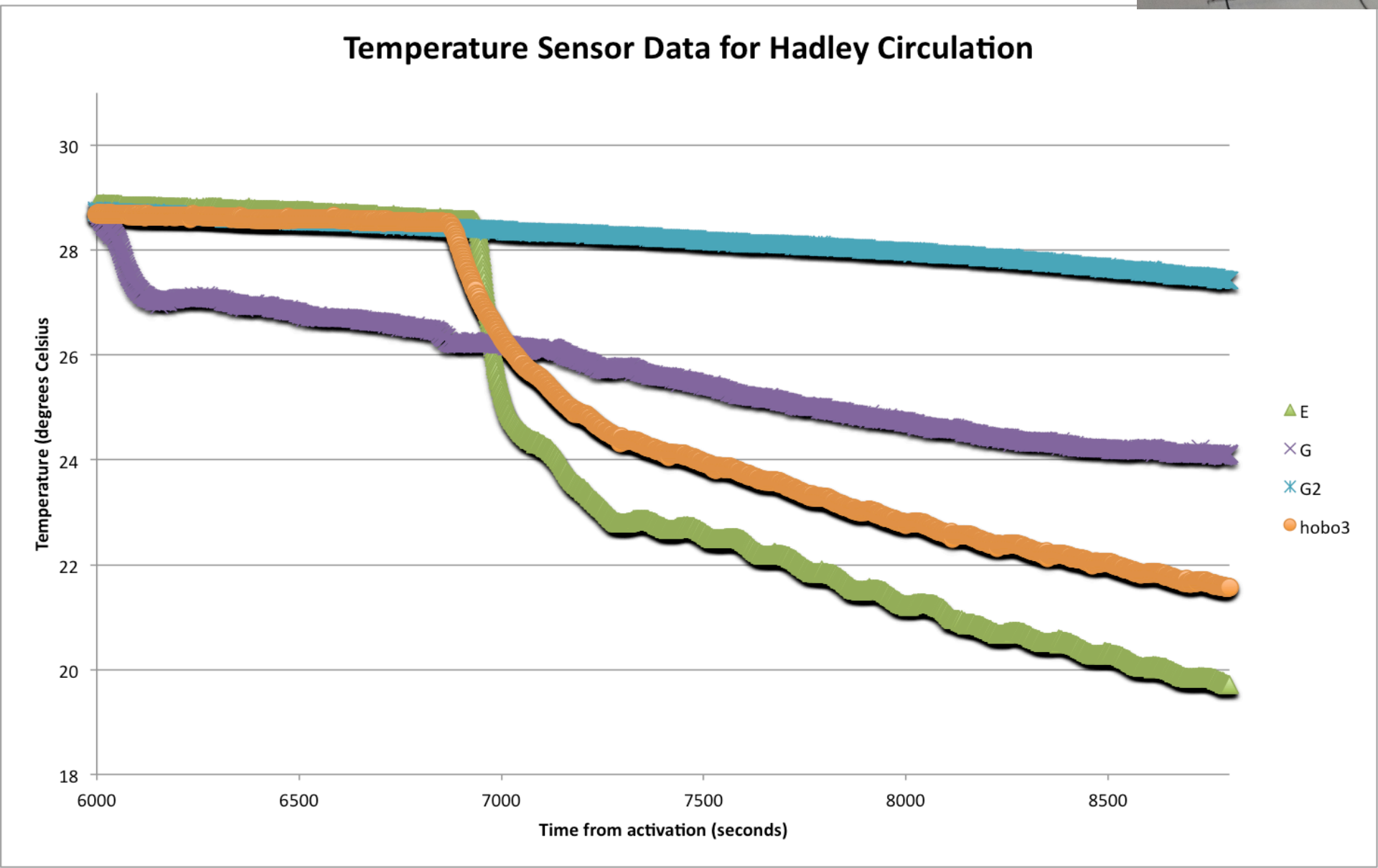


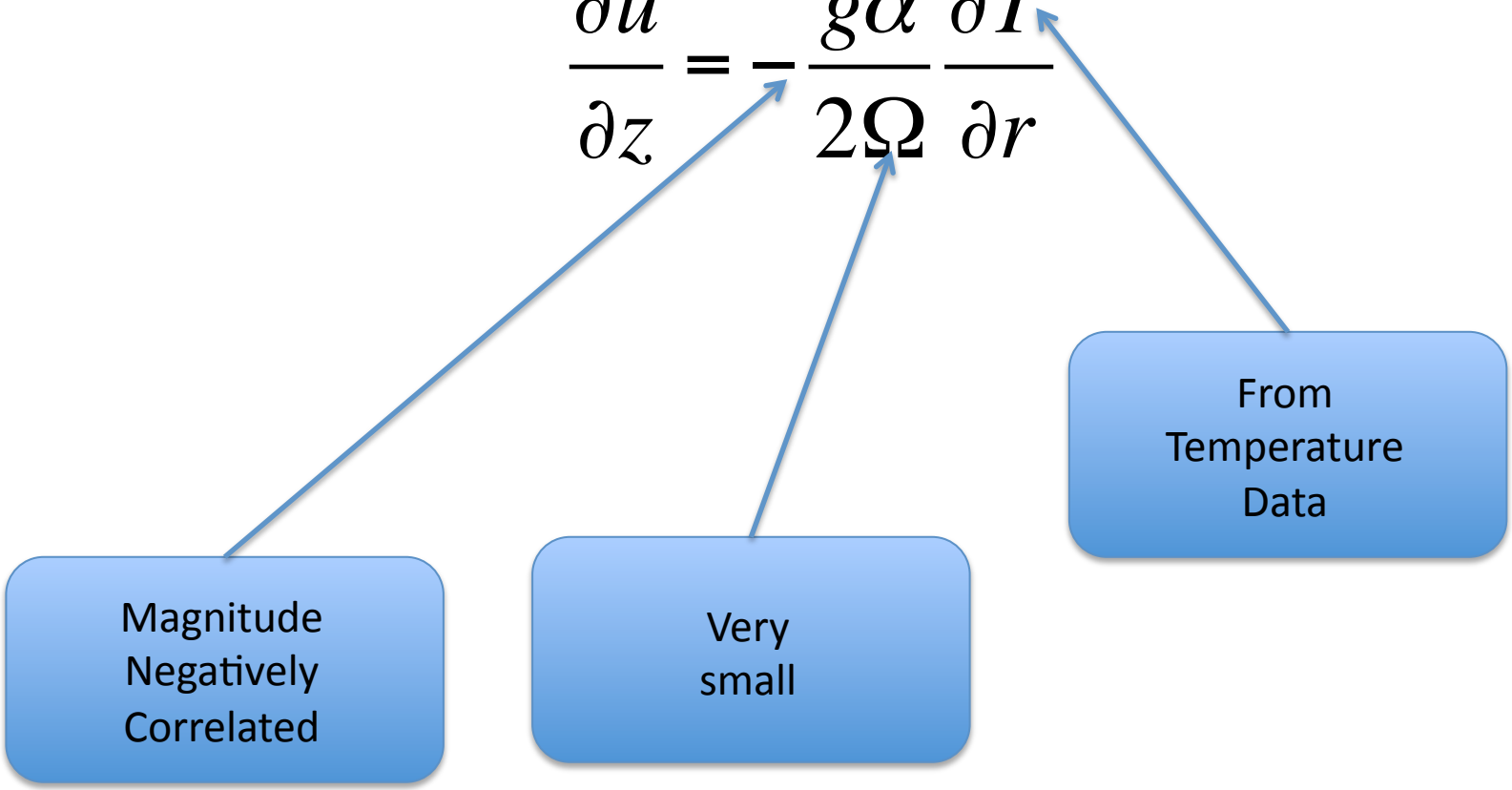


Temperature Data

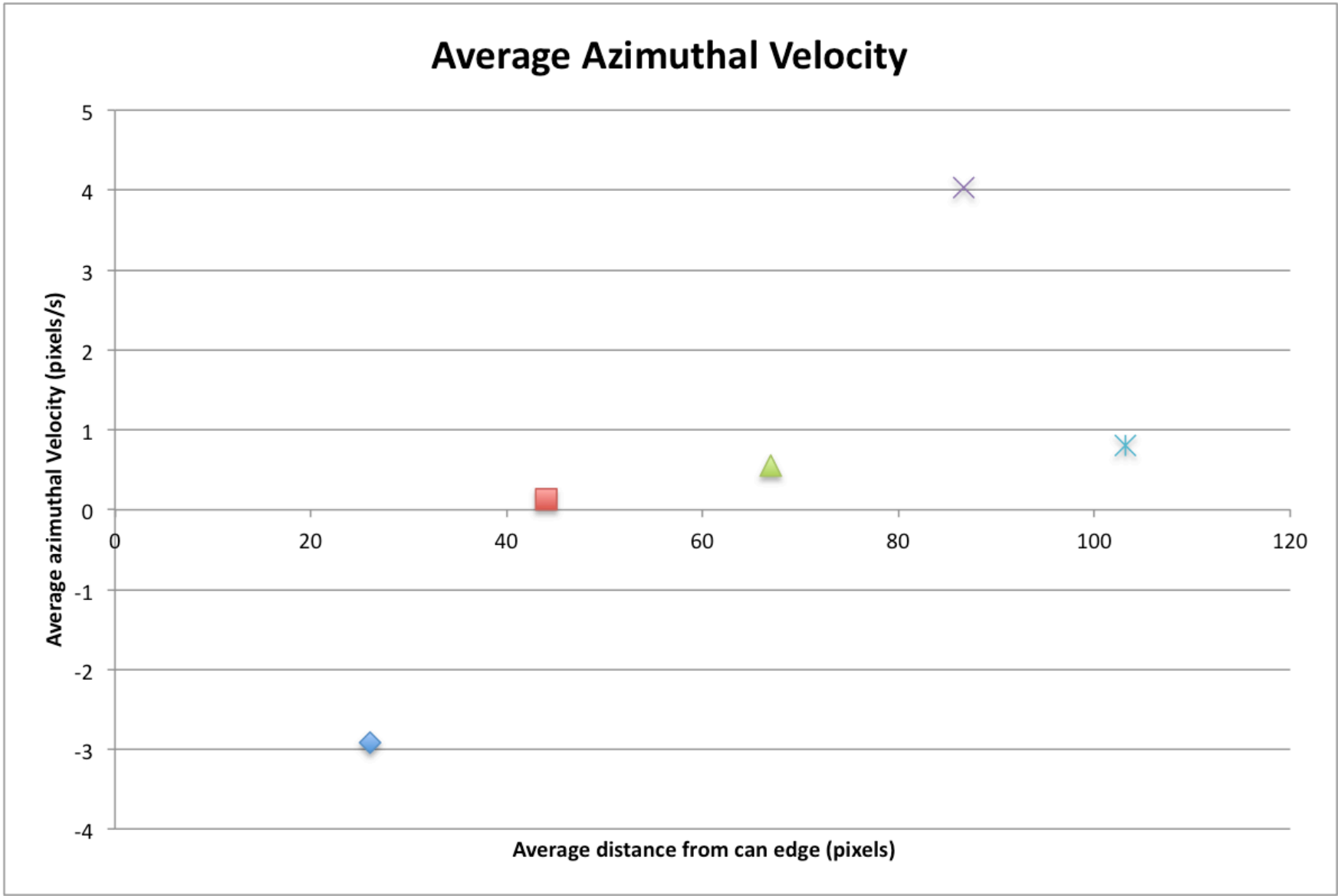
- Nonlinear decrease
  - First observed in second sensor from canister
  - Representative of convection
    - Colder, dense water sinks and passes the second senor
      - Same is true for third sensor, in both cases
    - First sensor exposed to warmer water
      - Same is true for fourth sensor, in both cases
      - Data not observed for fourth sensors due to time constraints
    - Explanatory of slight periodicity observed in temperature
  - Sharpest temperature gradients are somewhere between the canister and second sensor

Thermal Wind

$$\frac{\partial u}{\partial z} = -\frac{g\alpha}{2\Omega}\frac{\partial T}{\partial r}$$



Velocity Data

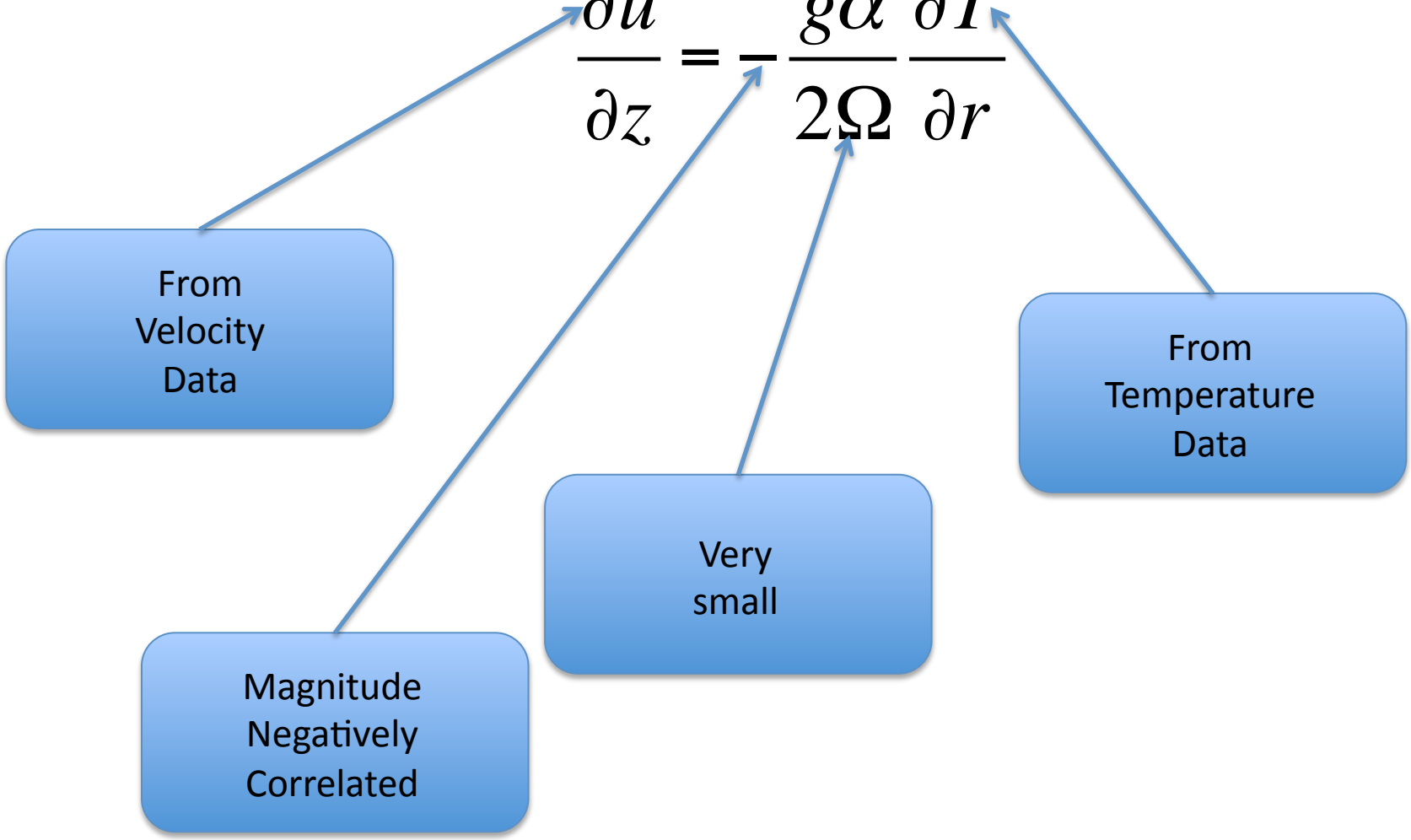


Velocity Data

- Initial Negative Velocity
  - Indicative of positive temperature gradient
    - Matches the observation from the temperature data
  - Very strongly negative
    - Indicative of strong thermal gradient
    - Again, as observed
- Large Positive Velocity
  - Near the edge
  - Indicative of negative thermal gradient
  - Expected result from initial convection
  - Difficult to explain; Need more temperature data

Thermal Wind

$$\frac{\partial u}{\partial z} = -\frac{g\alpha}{2\Omega}\frac{\partial T}{\partial r}$$



Conclusions

- Atmosphere
  - Similar to polar front
    - Greatest velocities with sharpest gradients
  - Thermal wind behavior
  - Apparent convection
    - Falling and rising air
- Experiment
  - At low rotation, able to mirror polar front experiment
    - Greatest velocities with sharpest gradients
  - Reflects thermal wind behavior
  - Observed convection
    - Farther sensors undergo temperature decrease earlier
- The experiment is a controlled environment in which to accurately develop the theory to explain atmospheric phenomena in the case of General Circulation