Time-Frequency Analysis and Filtering for Identifying Convectively Coupled Waves

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Project

This project uses UHF and VHF wind profilers in conjunction with satellite observed Outgoing Longwave Radiation (OLR), Cloud Archive User Service (CLAUS) brightness temperatures, QuikSCAT scatterometer winds, TRMM Precipitation radar data, and reanalysis in the equatorial Pacific region to identify and analyze atmospheric waves that organize convection.

Location and Data

Wind profilers have operated in the tropical Pacific for over a decade and have provided extensive wind data sets. The sparseness of observations in the tropics combined with the good vertical and temporal resolution of wind profiler observations make wind profilers a valuable resource for studying the atmospheric circulation and structure of waves.

Schafer et al. (2007) showed that wind profiler height coverage and data quality could be significantly improved using Coplanar Spectral Averaging (CSA). This method combines and averages spectra from coplanar beams (e.g. east and west beams), increasing the signal detectability and reducing errors associated with spatial variability of the wind field. Recent work has shown that spectral averaging improves signal detectability even when coplanar beams are unavailable. This poster focuses on observations at Christmas Island where we have reprocessed and merged a 17 year period of UHF and VHF observations.

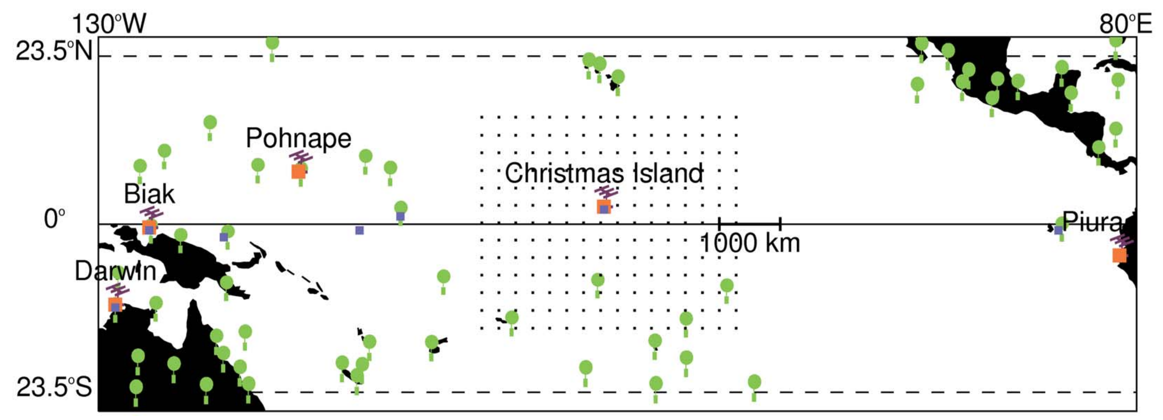


Figure 1 VHF wind profilers (red), UHF profilers (blue), rawinsondes (green), and a representation of the resolution of the NCEP-NCAR (RI RII) and ERA-40 reanalyses in the tropical Pacific region.

Zonal Winds

The NCEP-NCAR reanalysis (RII) and profiler zonal winds show good agreement with a clear seasonal cycle representing expansion and contraction of the Walker circulation. Composites show a maximum strength in the westerlies at about 14 km with profiler winds stronger than the reanalysis. Both show minimum strength in the easterlies near the tropopause from July to September. Low level easterlies are strongest near about 1.5 km from December to February. The height of the tropopause also shows an annual cycle with a minimum height from July to September when the Inter Tropical Convergence Zone (ITCZ) is furthest north.

Meridional Winds

The reanalysis and profiler meridional winds show similarities in structure, but the profiler circulation patterns tend to be stronger. During May to November, outgoing longwave radiation has been used to relate the circulation to convection in the ITCZ to the north of Christmas Island (not shown). This period corresponds to the period when convention is most active and the ITCZ is furthest north. OLR variance shows that convective activity peaks at about 7.5°N. During this period the composites show low level northward flow toward the region of convection and a return southward flow above. Both profiler and reanalysis composites show a complex Hadley like overturning structure with two cores of maximum southward flow. One core occurs near the freezing level while the other core occurs below the tropopause. The cause and timing of these two distinct maxima are currently being investigated but appear to be related to the morphology of shallow and deep convection.

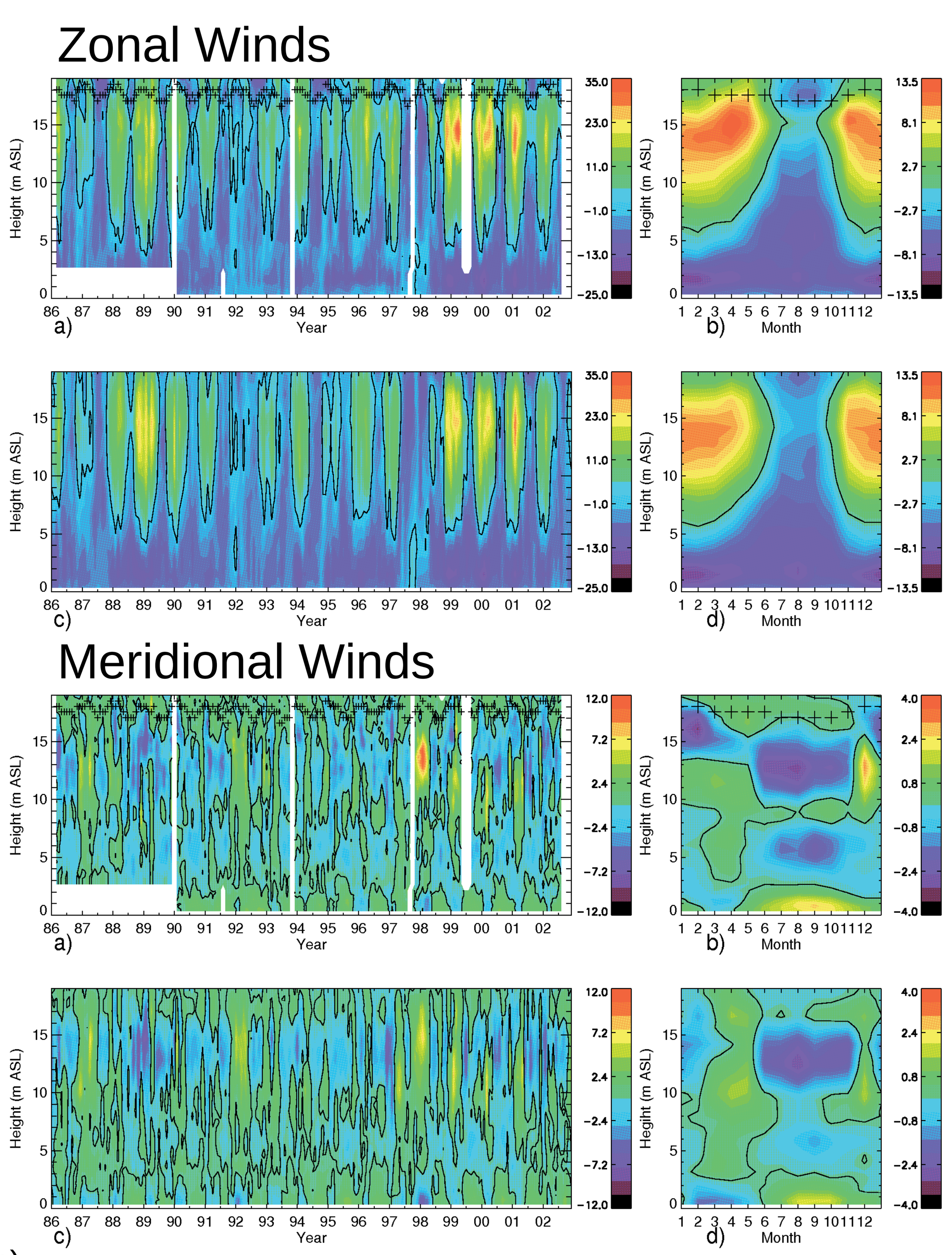


Figure 2 Zonal (top) and meridional winds (bottom) and tropopause height over Christmas Island for profiler (a) and reanalysis (c) as monthly medians and composite 17 year median months (b, d). Tropopause height (+) is derived from wind profiler reflectivity.

Wave Type Filtering

2-D Directional Filtering of OLR

Two-dimensional longitude-time cross-sections of OLR (Hovmöller diagram) are created by averaging data over latitude (+/- 15 degrees latitude about the equator). These longitude-time cross-sections are filtered using a similar 2-D filtering method as described in Wheeler et al. (2000). A two dimensional fast Fourier transform is computed on the Hovmöller image, frequencies and wave numbers that are not of interest are zeroed, and the inverse Fourier transform returns the 2-D filtered data. By only retaining spectral components where wave number and frequency have the same sign or where wave number and frequency have opposite sign, the 2-D filter becomes a directional filter retaining only eastward or westward propagating signals.

1-D Filtering of Wind Profiler Winds

Wind profiler and satellite observations have shown that waves are sporadic occurring at different times and with different phase and strength throughout the year. Because of this sporadic nature, identification of waves is best facilitated with time-frequency analysis. A sliding Fourier transform filter was implemented on wind time series, using a window of 30 days and slide step size of 1/2 the filter window length (15 days). To remove filter edge effects, only filtered data from near the center of each 30-day filtered time series is used in reconstructing the complete filtered time series. A similar time dependent filter can be constructed using a wavelet or S-transform.

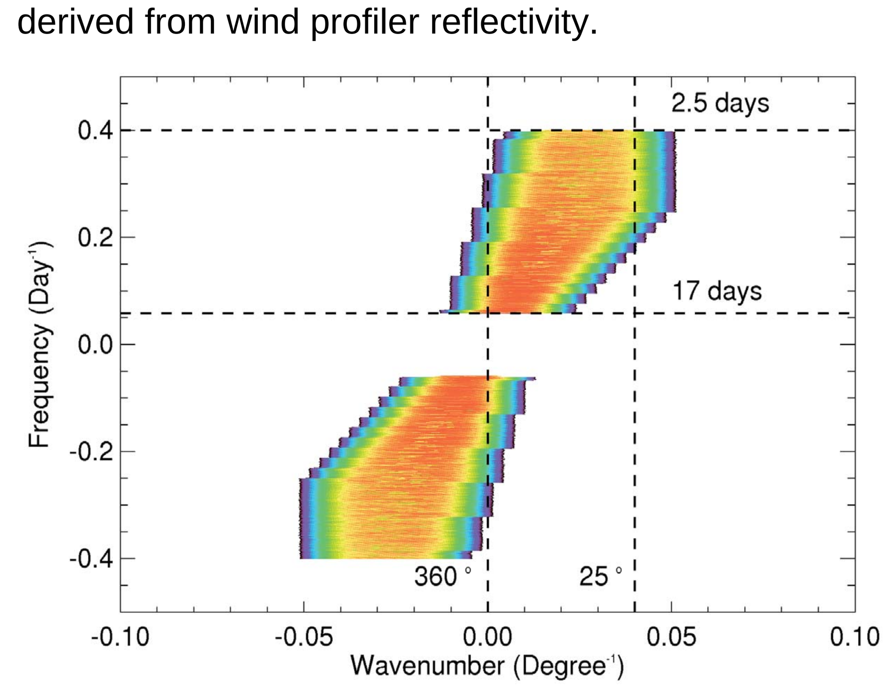


Figure 3. Power spectrum of Kelvin wave directionally filtered OLR. A shaped filter was used (based on the dispersion relationship for Kelvin waves e.g. Wheeler et al. 2000) and only frequency wave-number components in the top right and bottom left quadrants are retained.

Vertical Structure using Lagged Regression

To determine the relationship between wind profiler observed winds and OLR (a proxy for convection), a directional filtered time series of OLR at 157°W 7.5°N is correlated with Christmas Island wind profiler observed velocity as a function of time-lag and height. A least squares fit uses OLR as a predictor for the velocity profile. The least squares fit can be compared to a principal component analysis of wind profiler winds which is independent of OLR.

Statistical Structure of Kelvin Waves

A Kelvin wave is an eastward moving wave with a propagation speed of about 15 ms^{-1}, and dynamic fields shown theoretically to be symmetric about the equator. Observed convection, however, is typically asymmetric and concentrated in the ITCZ.

Lagged regression plots shows the statistical structure of Kelvin waves in wind profiler and OLR observations. Zonal winds below about 9 km are out of phase with those above, and the wave has a period of about 6-8 days. There is a vertical velocity maximum at about 10 km which is in quadrature with the phase of the zonal winds. Principal component analysis of the zonal winds also shows a profile where winds above in the upper Troposphere are out of phase with those in the lower Troposphere. For vertical velocity the PCA indicates a maximum near 10 km. These results present evidence that the observed structure of the winds may be related to convectively coupled waves.

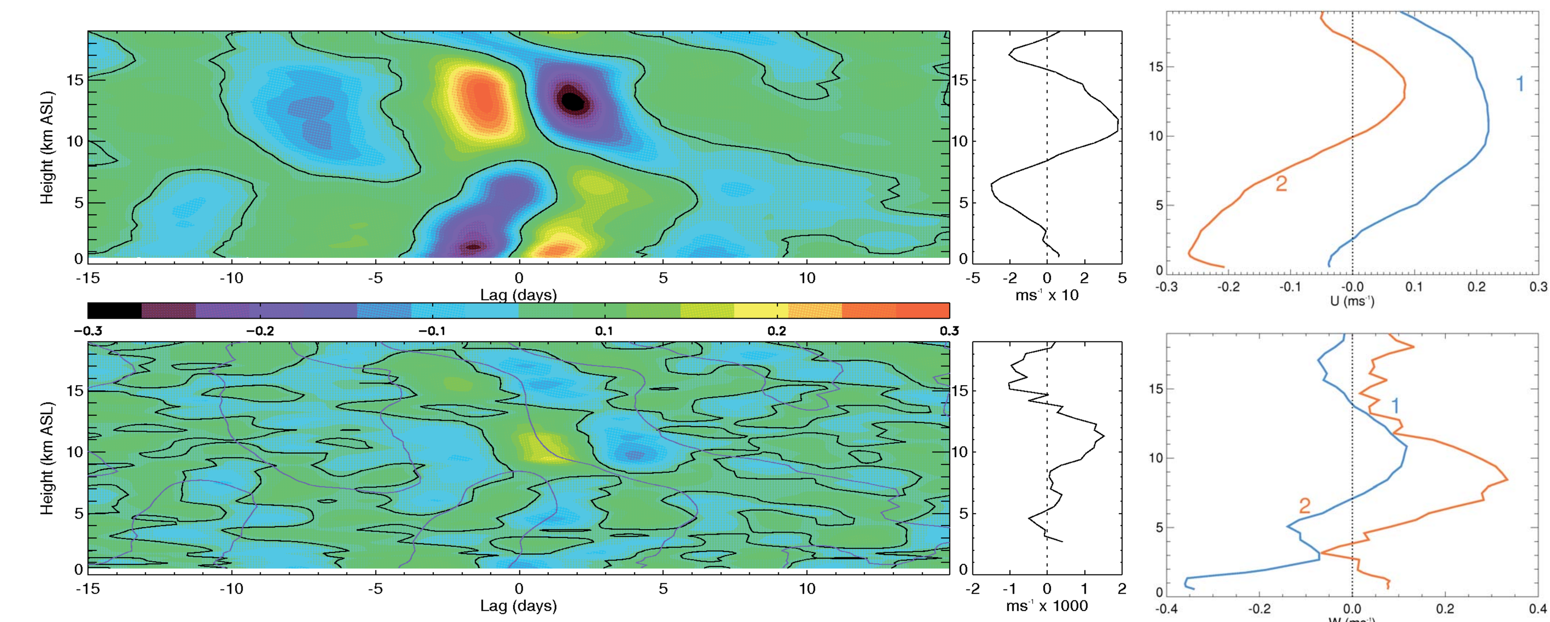


Figure 4. Wind profiler observed Zonal wind (top) and vertical velocity (bottom) correlated against 2.5-17 day eastward filtered OLR (lagged regression). Middle panels show velocity profiles from a least squares fit of velocity to filtered OLR. First and second vectors from a principal component analysis of wind profiler winds are shown in panels to the right (these are independent of OLR).

Structure of Individual Kelvin Waves

Individual Kelvin waves show significant variability associated with differences in location and intensity of convection. Because the waves are tied to convection, there is also a meridional wind response related to the embedded mesoscale convective system and storm morphology. To investigate variability in individual cases, directionally filtered CLAUS Brightness temperatures, OLR, and QuickScat Winds are used to isolate the propagating wave. Tracking of these disturbances in both Hovmöller diagrams and longitude-latitude image sequences is used to determine the time when the wave crosses Christmas Island and the north south location of any associated convection. The wind structure can then be studied using the wind profiler observations. The Hovmöller diagram removes information on the asymmetry of convection as it averages all latitudes into a single band. Therefore to investigate the impact of asymmetric convection on the wind structure, we are developing a cloud tracking algorithm.

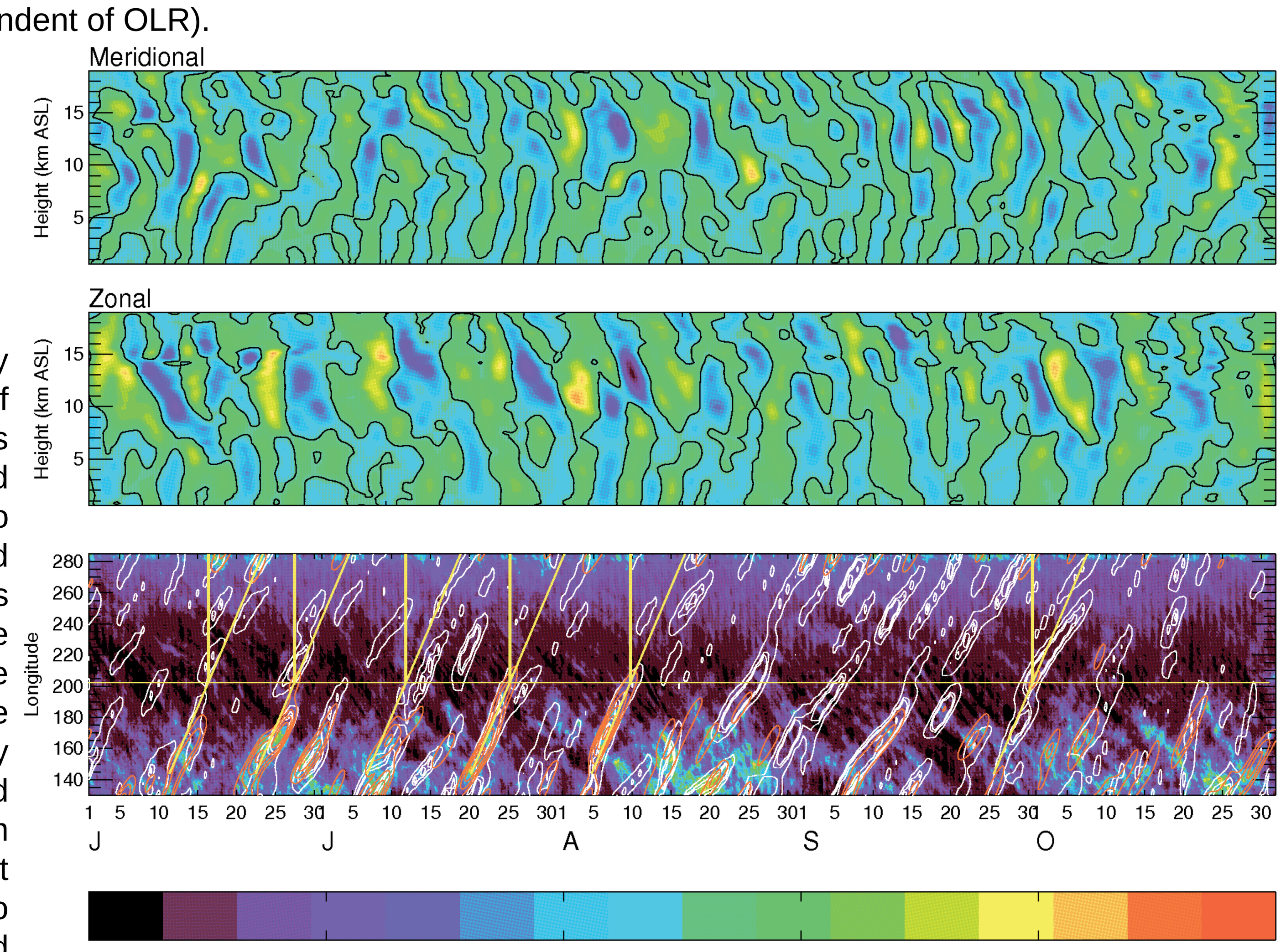
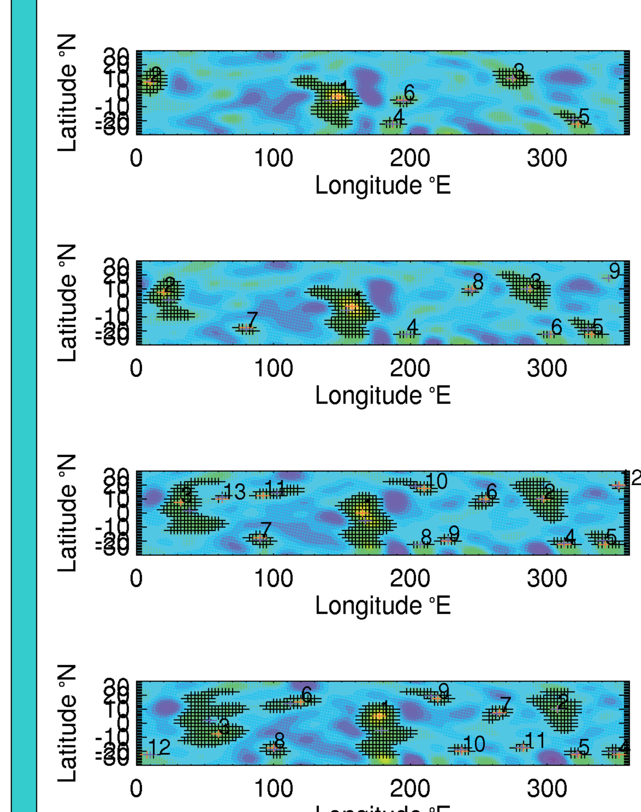


Figure 5 Wind profiler meridional and zonal 2.5-17 day slide-filtered winds (Top and Middle). Filled contours showing CLAUS brightness temperature observations. Over the filled contours we show Kelvin wave directionally filtered CLAUS contours (red) and QuikSCAT surface winds (White). Yellow lines mark the time that a brightness temperature maximum crosses the longitude of Christmas Island and the 15 ms^{-1} propagation speed line.



Tracking Algorithm

- Classify contiguous OLR anomalies (clusters)
- Analyze all clusters in 3 consecutive frames
- Link clusters by minimizing a cost function that is based on mean OLR, speed, direction, and cluster size

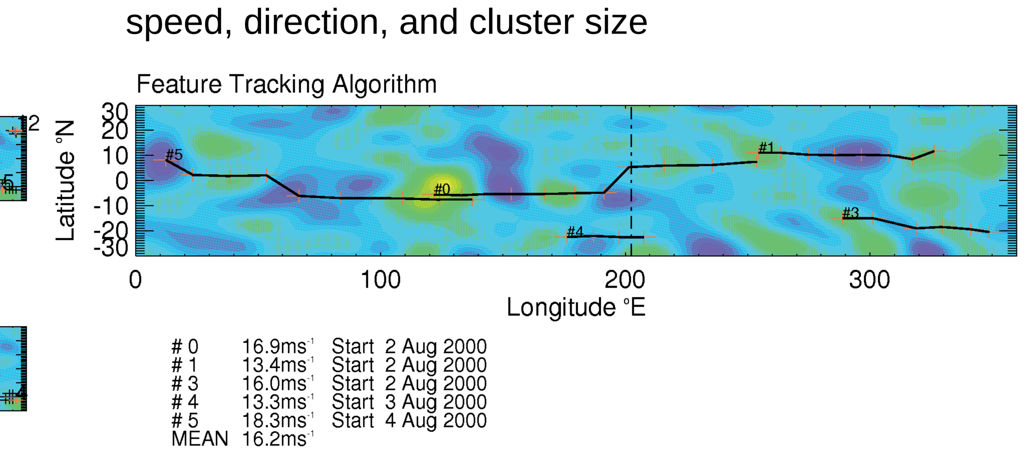


Figure 6 Tracking of OLR anomalies. Clusters are defined for contiguous OLR anomalies (left). Clusters in adjacent frames are linked to form tracks (right). The start time and average speed is shown for selected tracks.

Continuing Work

We are continuing to identify interesting wave case studies and undertaking statistical studies that can be used to understand how waves impact convective morphology. The tracking algorithm is being developed to use QuikSCAT winds so that waves can be tracked during dry phases where there is no observed coupled convection. TRMM Precipitation Radar storm height observations and convective-stratiform classifications are being used to relate convective morphology to the phase of convectively coupled waves. This work was supported by NSF Grant ATM 0116178.

Schafer, R., S. K. Avery, K. S. Gage, G. N. Kiladis, 2006: Wind profiler observations over the central equatorial Pacific: Optimizing processing to improve quality and height coverage. *J. Atmos. Oceanic Tech.* Publication Pending

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