Characteristics of and Relationships between Surface Heat and Moisture Fluxes and Ocean-Atmosphere Variability

Carol Anne Clayson, WHOI
Brent Roberts, MSFC

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Overall goal of research

- Air-sea interaction through surface fluxes of heat and moisture, combined with other weather properties, across variety of spatial and temporal scales

- Seeking to understand:
  - The variability and extremes in air-sea fluxes of heat and moisture in context of water and energy cycle
  - How distribution of fluxes varies of time, location, differing weather and climate states

- Using satellite data sets (ISCCP, SRB, SeaFlux, GSSTF, TMPA, HOAPS, GPROF) and MERRA
Questions addressed

- How do distributions of heat and moisture fluxes over the global oceans vary in space and time? What is the relationship to surface and cloud properties?

- What local weather states as evidenced by cloud and surface properties are associated with the surface heat and moisture flux distributions? Do changes over time to the distributions occur because of changes in frequencies of weather states or because of changes in the weather states themselves?

- How do these distributions and weather states vary within the larger-scale climate variability? To what extent can this be determined given the changing sampling characteristics over a 20 year period?
Example distributions

Latent heat flux 1999
95th Percentile

LHF September 1999

Wind Speed September 1999

Qs - Qa September 1999
Extremes in LHF

95th Percentile MERRA LHF 1999

95th Percentile SeaFlux LHF 1999
Extremes in winds
Extremes in Qs-Qa

95th Percentile MERRA Qs-Qa 1999

95th Percentile SeaFlux Qs-Qa 1999
Extremes in LHF
Extremes in winds
Extremes in Qs-Qa

5th Percentile MERRA Qs-Qa 1995

5th Percentile SeaFlux Qs-Qa 1999
Weather Regimes Example

- Use of ISCCP cluster weather states (Jakob and Tselioudis 2003)
  - Tropical convection and MJO (Tromeur and Rossow, 2010; Chen and Del Genio, 2009)

- Datasets:
  - ISCCP Extratropical Cloud Clusters (35N/S, 2.5°x2.5° 1985-2007, 3-hr)
  - SEAFLUX (1998-2007,0.25°x0.25° 3-hr), LHF/SHF/Surface Variables

- Product Homogenization:
  - Fluxes regridded and resampled to ISCCP 2.5x2.5
  - ISCCP 3-hr used to assign a daily class based on the most frequent cluster
Tropics

Mean LHF (W m$^{-2}$)

- Mesoscale Convection
- Isolated Convection
- Scattered Cumulus
- Clear Skies

- Mesoscale & Congestus
- Thin Cirrus
- Marine Stratus
Decomposition of surface fluxes by weather state

- Weather regimes result in distributions of fluxes with different mean and extreme characteristics

- Associated with changes in means

- Both wind speed and near-surface humidity gradients are particularly well stratified, though the latent heat flux means are less so
  - Indicates potential compensations
Compositing methodology

- Conditionally sample data using weather state classification (WS1-WS8; most convective to least convective)
- Further sampled based on compositing index to evaluate low-frequency coupled variability
- Use NOAA Climate Prediction Center (CPC) indices for ENSO and MJO

Examining differences in means can be decomposed as changes in class mean (A), changes in RFO (B), and covariant changes (C)

\[ \Delta \bar{X}_{(2-1)} = \sum_{i=1}^{K} RFO_i \delta \bar{x}_i + \bar{x}_i \delta RFO_i + \delta \bar{x}_i \delta RFO_i \]

\[ \begin{align*}
A & \quad B & \quad C \\
\end{align*} \]
MJO Composites – Decomposition into Weather states

- Decompose LHF into weather state means and relative frequency of occurrence (RFO)
- Systematic variations of both weather state means and RFO with MJO index
- Both variations contribute to total impact of a given weather state on mean energy exchange associated with MJO evolution
Example: Climate regimes

- Composite MJO based on index strength not time-lagging
- All three regions typically show increased evaporation during convective phase and decreased evaporation during suppressed phase
- The Indo-Pacific region changes → more wind-driven Eastern Pacific changes → more near-surface moisture gradient changes
- But: EIO more coherent near-surface moisture changes than WP
**ENSO Composites by strength**

- West Pacific (130E-150E) latent heating anomalies primarily driven by QSQA anomalies
  - For MJO, near-surface wind speed was also anti-correlated but it was stronger than QSQA

- The East Pacific (130W-110W) LHF acts to damp the existing SST anomalies
  - Unlike on MJO time scales, wind speed and QSQA are positively correlated
MLD and surface flux effects on SST tendencies

The mixed layer depth is an important contributor to the observed surface heat flux tendency pattern.
- EIO and WP: deeper ML in convective; EP: slightly deeper ML in suppressed phase
- WP: LHF variability has roughly same effect on SST tendency throughout MJO. EP: LHF much higher effect on variability during convective phase
- EIO: Even shallower ML in suppressed phase, but still large LHF due to Qs-Qa difference: LHF variability strongest effect during suppressed phase
Summary

- Cloud-based weather states can be used to provide improved understanding of surface energy flux variability.
- MJO variability is particularly well decomposed using ISCCP weather regimes from convective to neutral and suppressed states.
- Different regions in the tropics show MJO and ENSO variability being driven by different processes.
- Even when total LHF differences are equivalent, if winds versus $Q_s - Q_a$ effects (with resulting MLD differences) occur, changes in LHF different effects on temperature tendency:
  - For example: fair weather cirrus vs. marine stratus vs. clear skies during suppressed conditions.

Both the weather state and the ML state affect resulting impacts on SST.