The Coupling of Convection, Large-Scale Atmospheric Dynamics, and Sea-Surface Temperature Hot Spots as Characterized by **MODIS**, TRMM, and ECMWF-Interim Reanalysis Data

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Overarching Motivations

•Understanding ocean-atmosphere interactions over the tropics is paramount to understanding tropical climate and even climate sensitivity

•Observed has been the relatively narrow SST range over which deep convection occurs, with the onset between 26-28˚C, peak convective activity between 29.5˚C-30˚ [e.g. Waliser and Graham 1993; Kubar et al. (2011); Behrangi and Kubar (2012)], and drop-off beyond these SSTs, the latter related to the formation of SST hot spots (Waliser 1996)

•While Waliser (1996) characterized composites of monthly large-scale circulation, cloud fields, and ocean profile temperatures the month(s) before, during and after hot spots (defined as monthly 10^6km^2 regions in which monthly SSTs>29.75˚C), less focus was placed on individual hot spot events and the relationships between hot spot intensity, size, and its interplay with large-scale forcing and convective strength.

•We have the advantage of high-temporal resolution multi-sensor satellite data (e.g. **MODIS** and **TRMM)** as well as co-located reanalysis data **(ERA-Interim),** to characterize the horizontal, vertical and temporal evolution of different cloud types, large-scale dynamics/thermodynamics, and precipitation as they relate to hot spots from various time scales (e.g. synoptic to interannual)

Specific Objectives

•Characterize relationships between SSTs, different convective cloud types from **MODIS**, and large-scale dynamics from ECMWF reanalysis (**ERA-Interim)**

•Using the **Aqua MODIS** joint L3 histograms, partition MODIS ice cloud types as a function of visible optical depth τ as thin cirrus, anvil, and convective core clouds

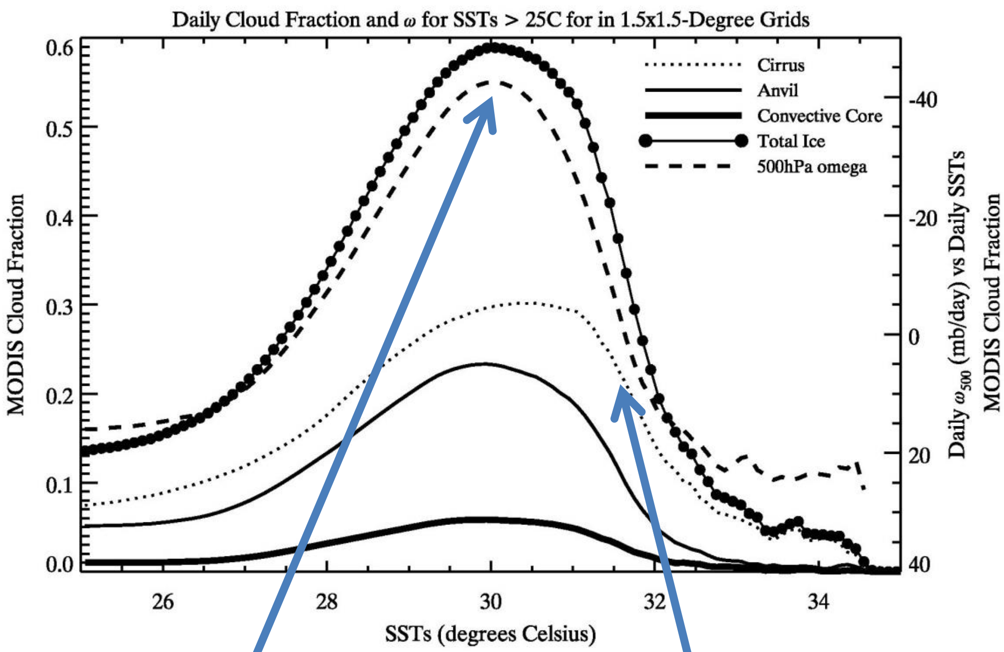
•**Cirrus clouds** have $0<\tau<5$, **anvil clouds** $5<\tau<30$, and **convective core clouds** $\tau>30$ – thus **cirrus clouds** have a TOA warming effect, and **anvil and convective core clouds a** net TOA cooling effect (based on Kubar et al. 2007)

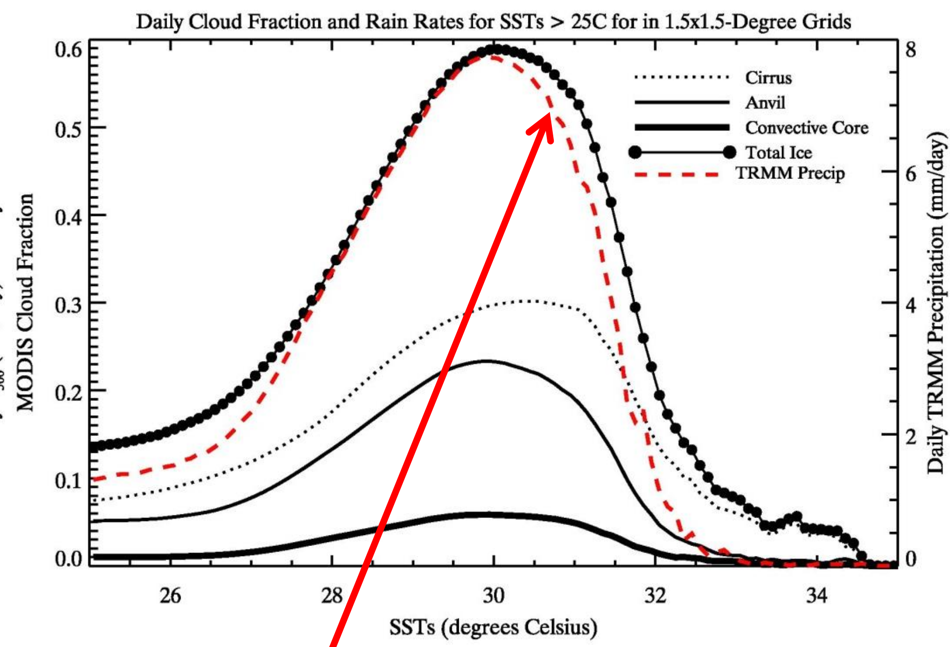
•Perform time-series analyses in domain-averaged 20˚longitude x10˚latitude boxes, and construct latitudinally-averaged Hovmoller diagrams (between 0-10˚S) to quantify the importance of SST hot spot formation on the spawning of deep convection via relationships with upward motion and low-level convergence

•Examine synoptic variability of SSTs, vertical cloud profiles, and large-scale dynamics and moisture profiles vertical profiles over favorable hot spot selection regions

•Investigate the occurrence of a "predator-prey" type of relationship involving convection (predator) and prey (hot spots)

Ice Cloud Fraction, ω_{500}, and Rain Rates vs SSTs



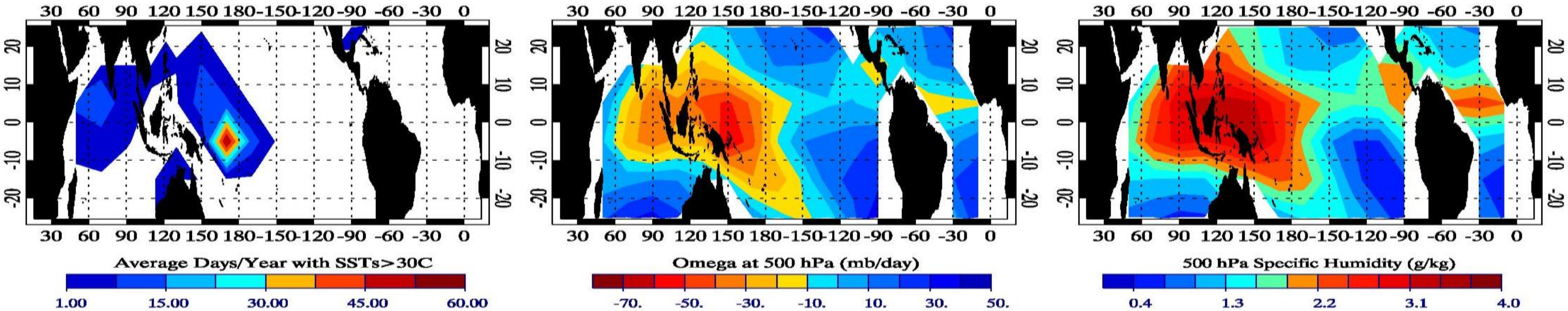


Total Ice Cloud Fraction and ω_{500} both peak at SSTs ~ 30˚, a slightly higher SST than Waliser and Graham's (1993) analysis

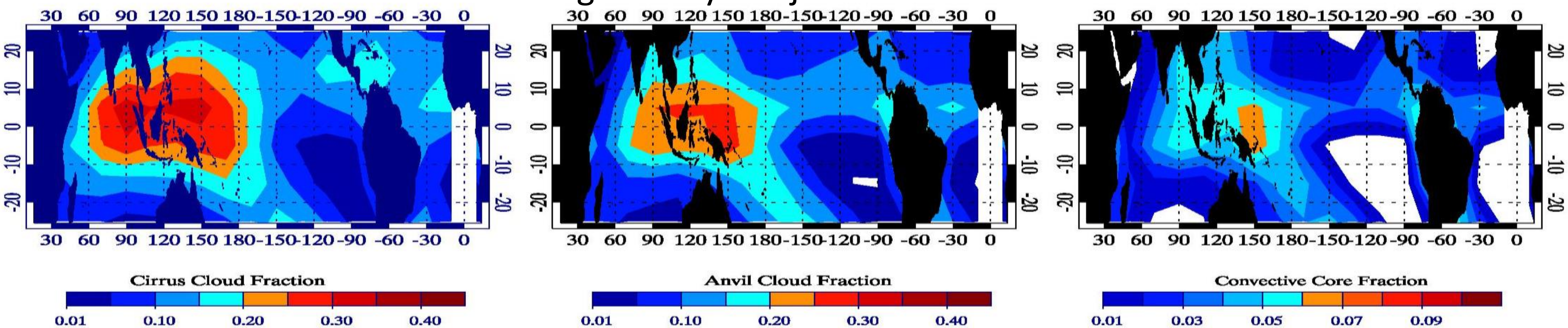
Cirrus clouds peak over warmer SSTs and may be a positive feedback with SSTs

TRMM rain rates peak at 30˚C, but then drop off more quickly than cloud fraction, since optically thinner clouds occur over higher SSTs and rain less

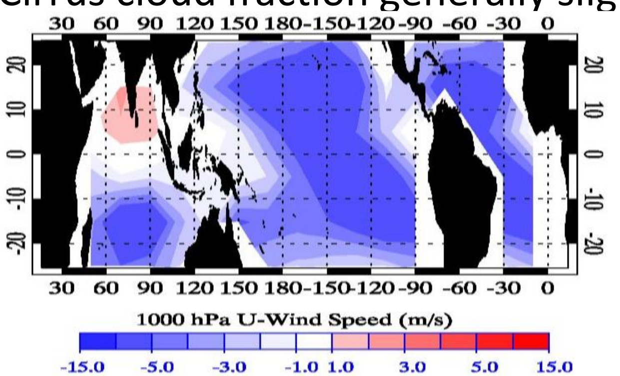
Climatology of SST Hot Spots, Clouds, and Large-Scale Circulation in 20˚lon x 10˚lat boxes



•Box between 160˚-180˚ and ~0˚-10˚S generally has just under a 2 month-duration with SSTs>30˚C



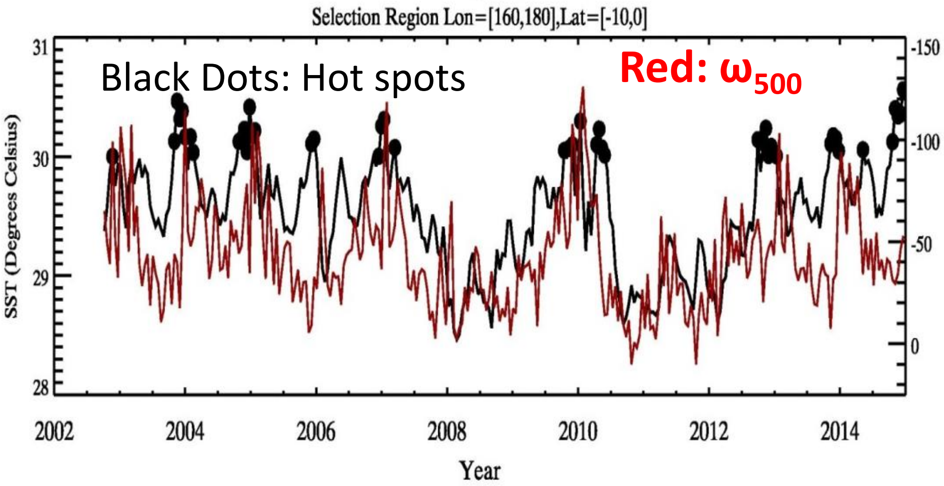
•Cirrus cloud fraction generally slightly larger with greater areal coverage than anvil clouds

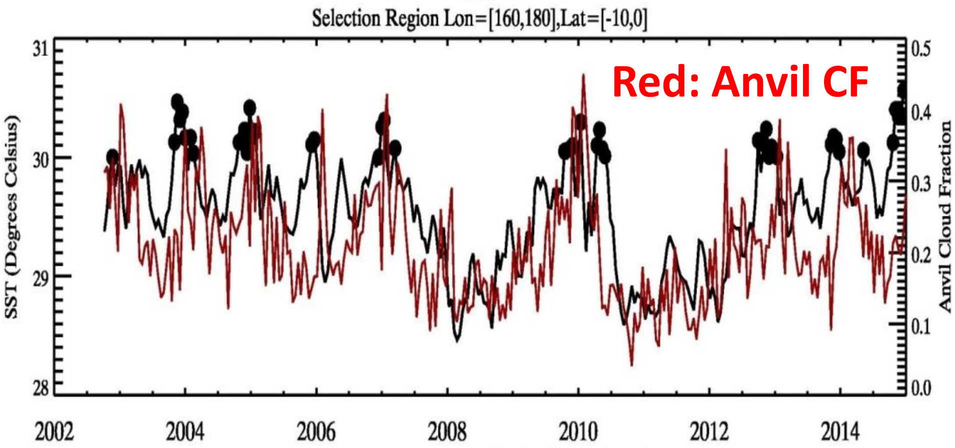


•Generally easterly low-level winds throughout tropics, except near zero mean u-winds over the warm pool, where winds can be easterly or westerly (e.g. during westerly wind bursts)

Time Series of ω_{500} and Anvil Clouds and SSTs over West & East Selection Regions

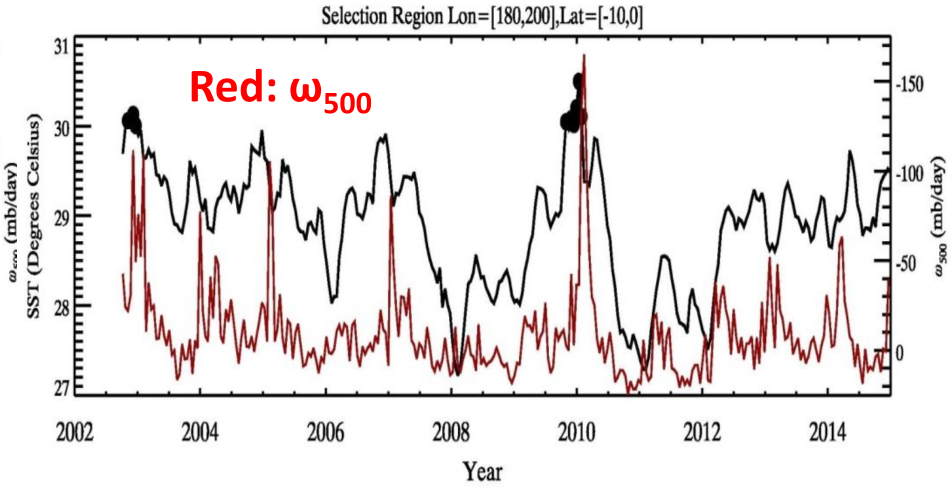
160˚-180˚, 0-10˚S (Black: SSTs)

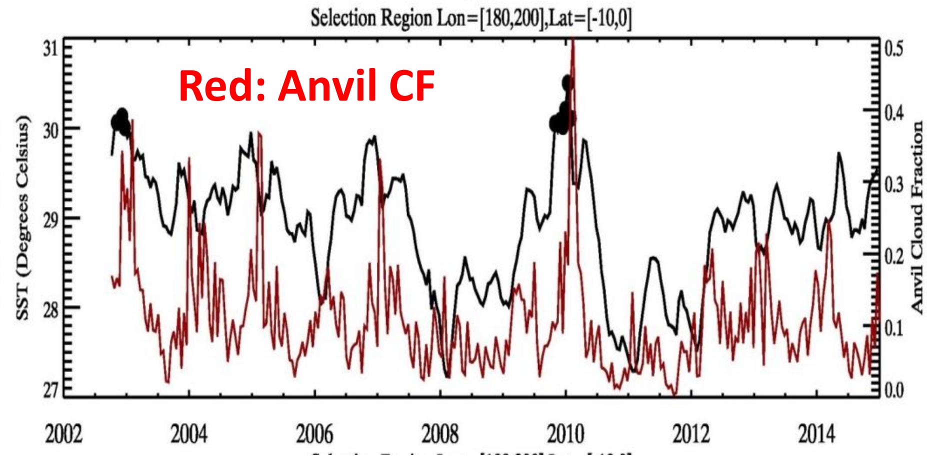




•Both ω_{500} and Anvil CF clouds peak in intensity/coverage just following (~15 days to ~1 month) after peak SST hot spot, usually at the end of each calendar year

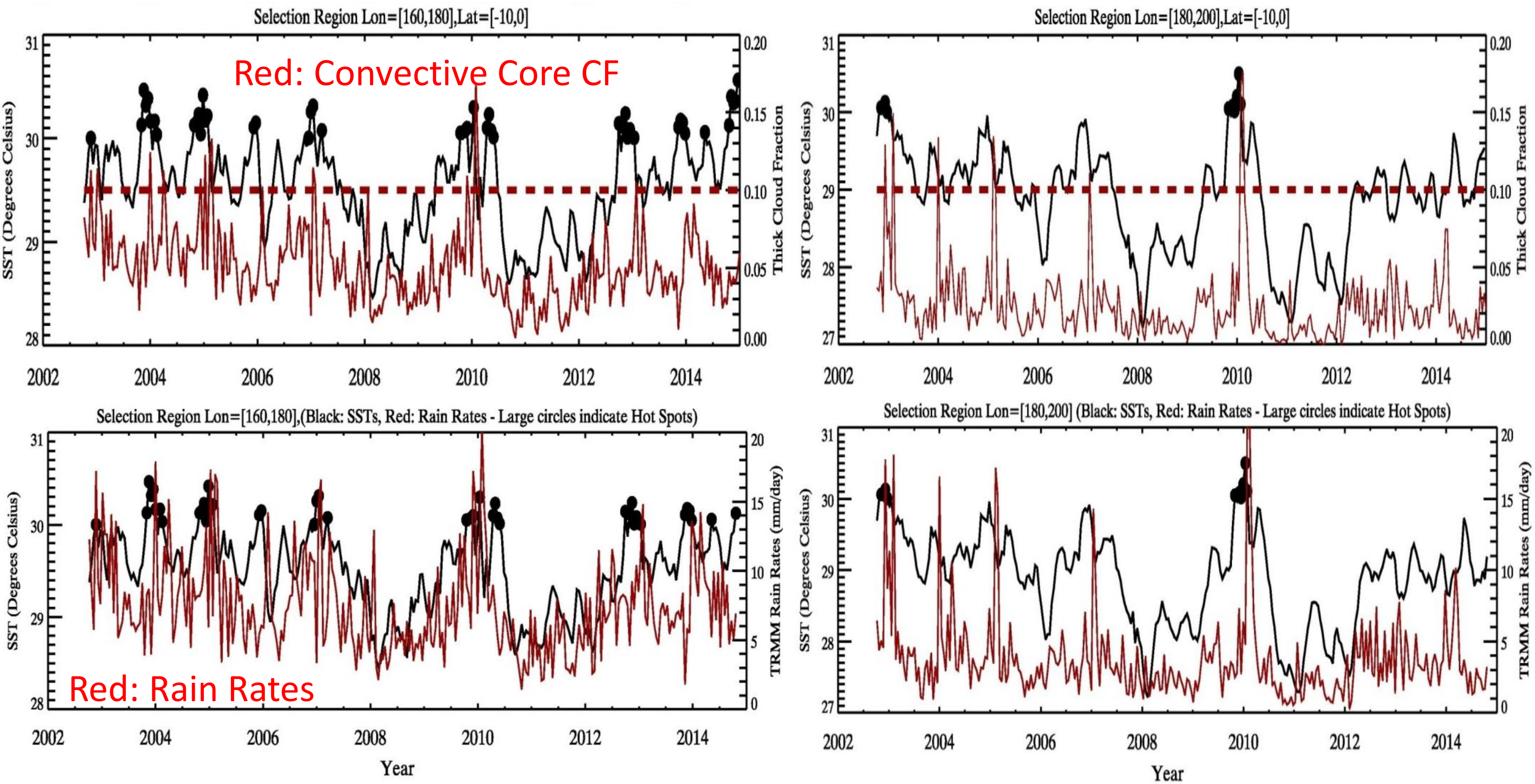
180˚-200˚, 0-10˚S (Black: SSTs)





•Moderate El Nino late 2009/10 marked by strongest hot spot of the record, with strongest upward motion and largest anvil cloud coverage just after SST peak

Time Series of Convective Core CF, Rain Rates, and SSTs over West & East Selection Regions



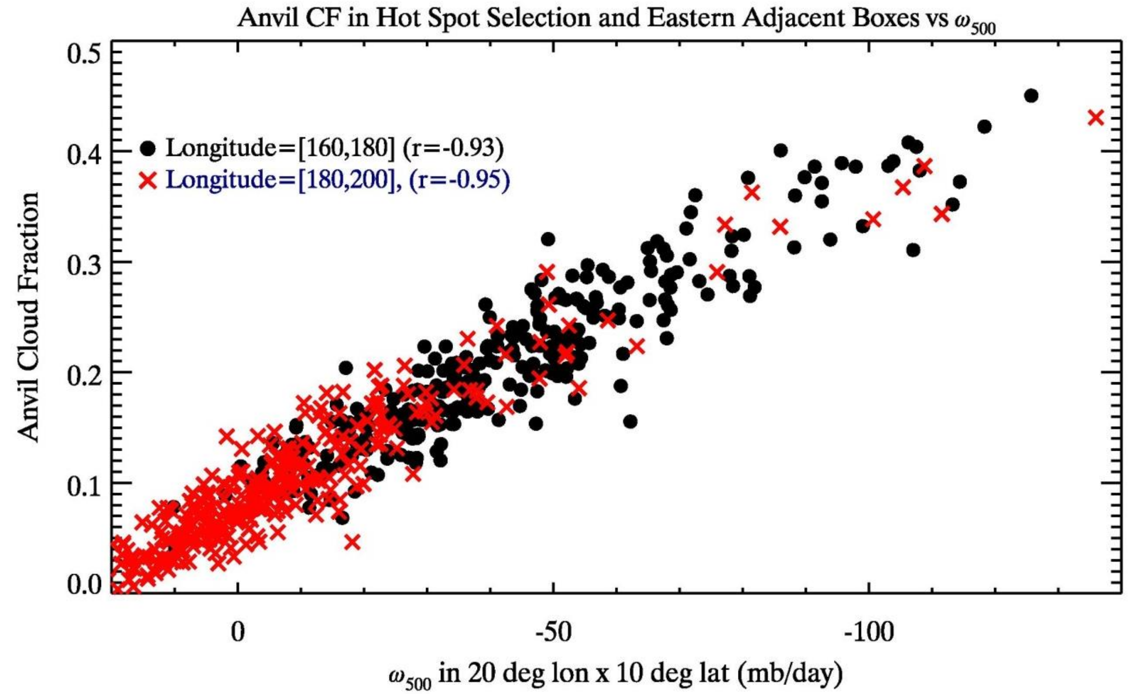
- Pulses of convective core cloud fraction (e.g. CF>0.1) and corresponding heavy rain rates during the decay stage of hot spots
- Lots of shorter-term convective and precipitation variability as well

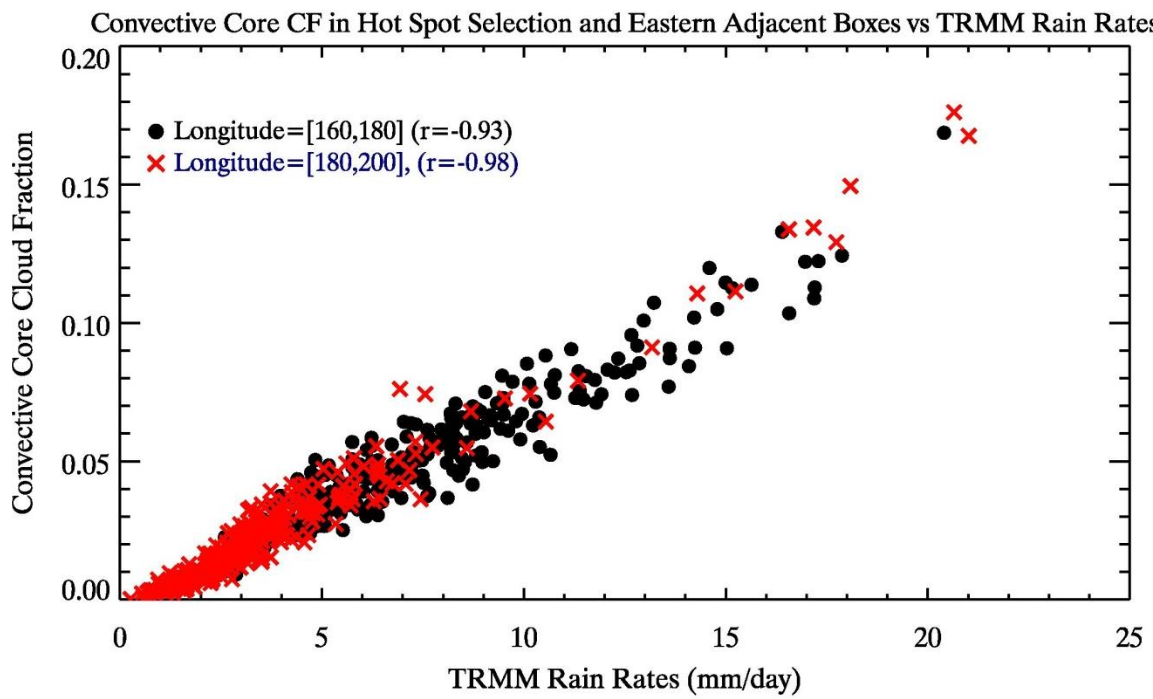
- Greatest convective core cloud fraction (top) and rain rates (bottom) just after the SST hot spot peak in late 2009/early 2010
- Other pulses of convective core cloud fraction/rain follow high SSTs (whether or not fully-fledged hot spots)

Summary of Cloud, ω, and Rain Rate Relationships over Primary Hot Spot Region [160˚,180˚] and Eastern Adjacent Regions

- In both west and east 20˚x10˚ boxes, anvil CF and ω_{500} are tightly correlated with each other, as are convective core cloud fraction and TRMM rain rates

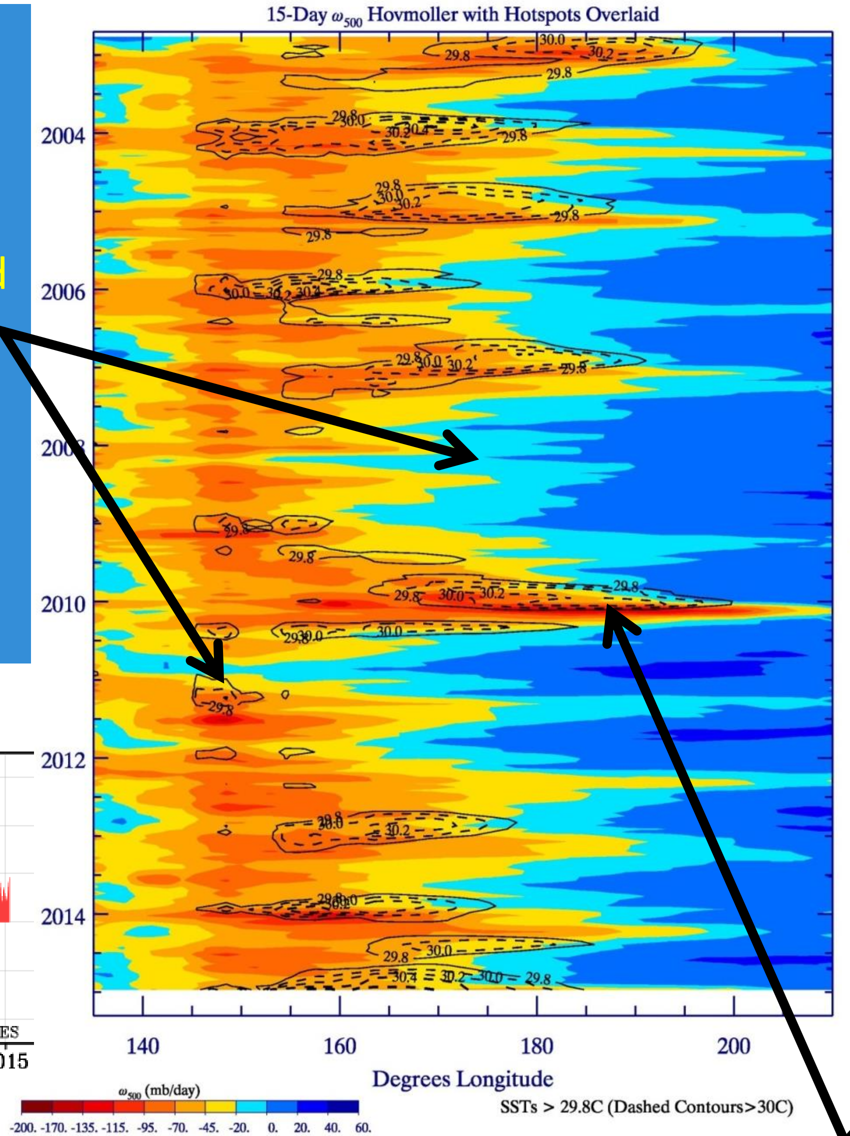
- The latter finding is consistent with Kubar et al. (2007) ("Radiative and convective driving of tropical high clouds), but that study used MODIS and AMSR-E and examined regions in the north Pacific ITCZ

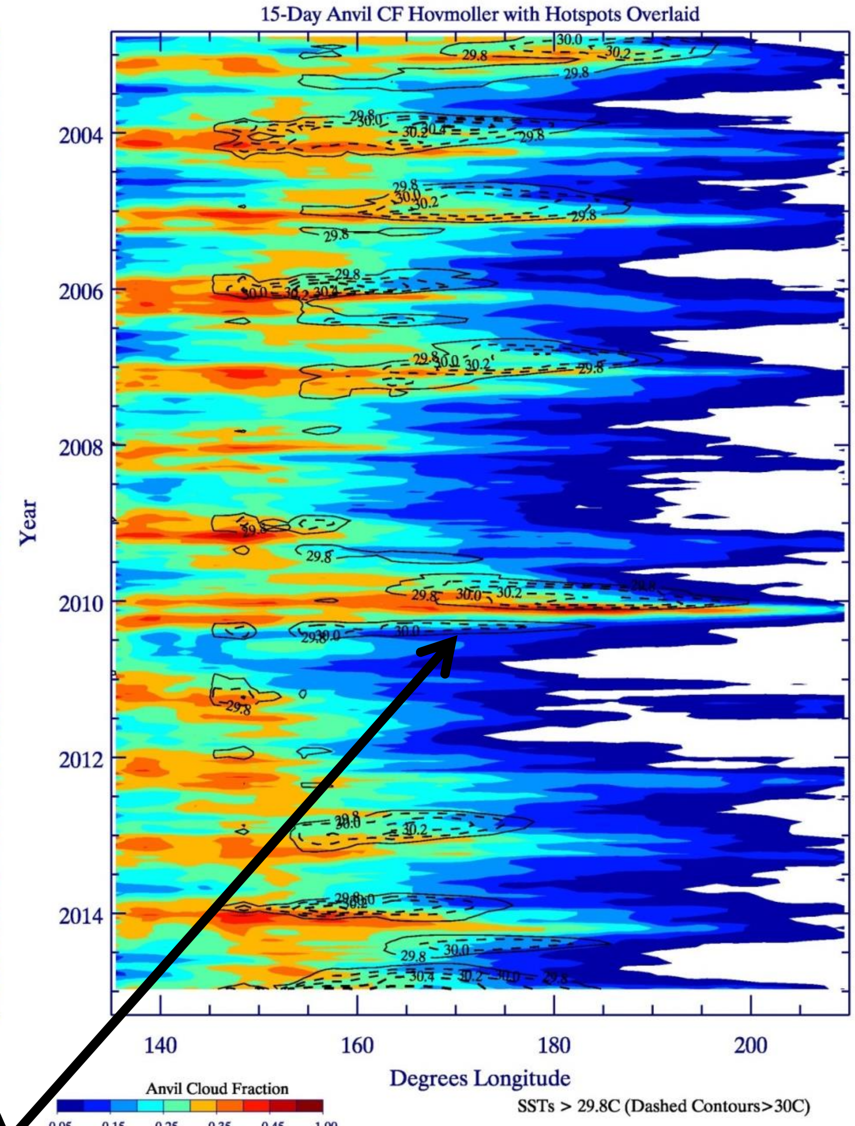


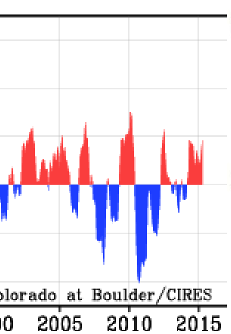


15-Day Hovmoller Diagrams over entire record (2002-2015) of ω_{500} Anvil CF with Hotspots Superimposed (Dashed Contours: SSTs>30˚; Solid: SSTs=29.8˚

- La Ninas (late 2007-2008 and late 2010-2011) – small or no hot spots





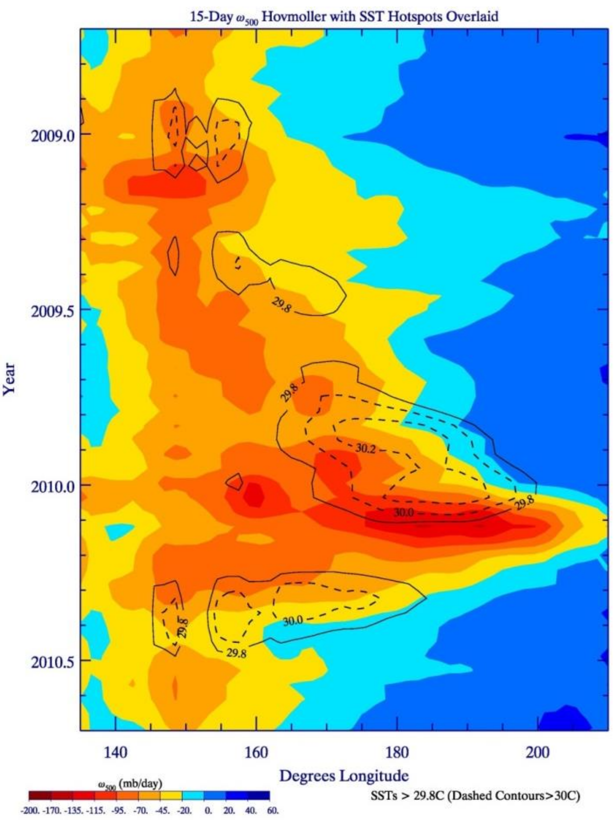


Moderate El Nino (late 2009/10): eastward propagation of large and strong hot spots, with large area of strong upward motion and widespread anvil CF

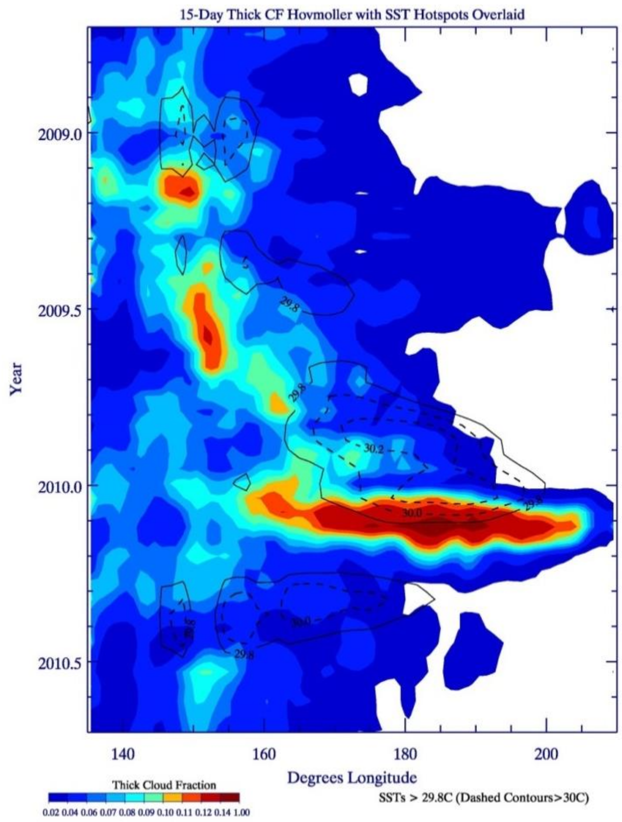
“Zoomed-In” Hovmoller Diagrams during 2008-2010

With Hot Spots Superimposed (Dashed Contours: SSTs>30˚; Solid: SSTs=29.8˚)

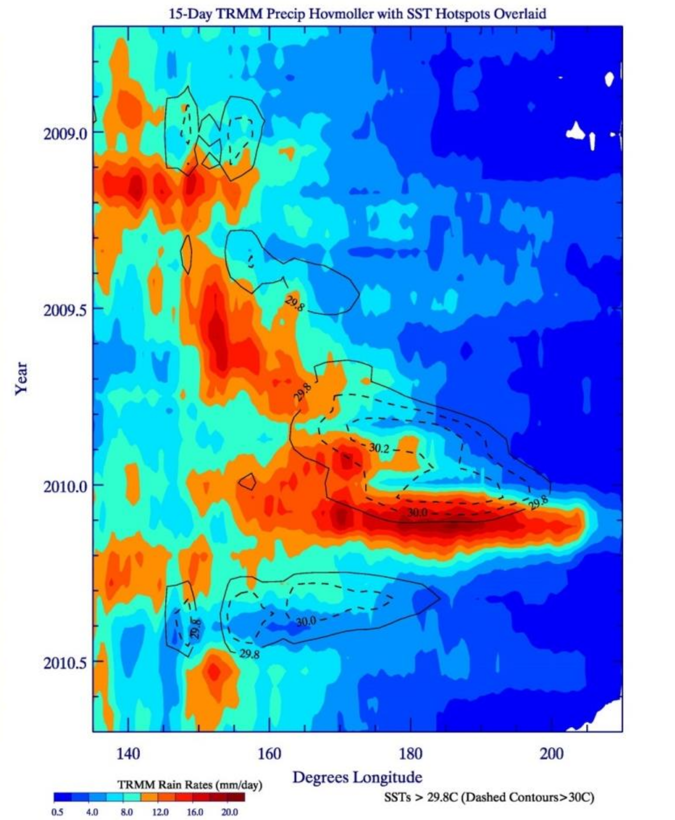
ω_{500} (late 2008-late 2010)



MODIS Convective Core CF



TRMM Rain Rates

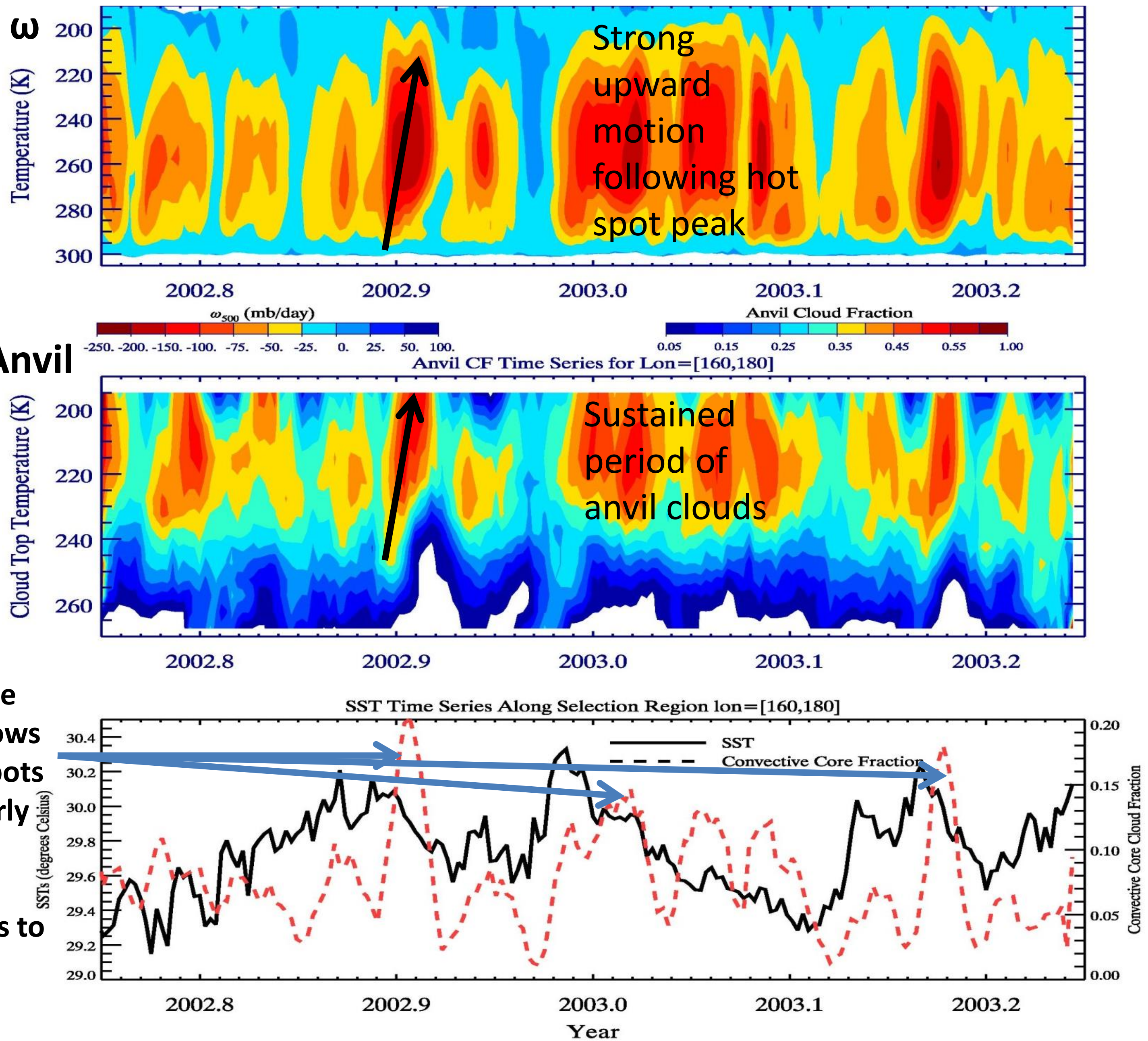


- Moderate El Nino during late 2009-early 2010; eastward-propagating hot spot with SSTs well above 30.2˚ for a few months → strong upward motion, significant and organized convection, and intense precipitation between 160˚-200˚ during the hotspot decay stage

Zoomed in Vertical Profiles for Primary Hot Spot Region (1)

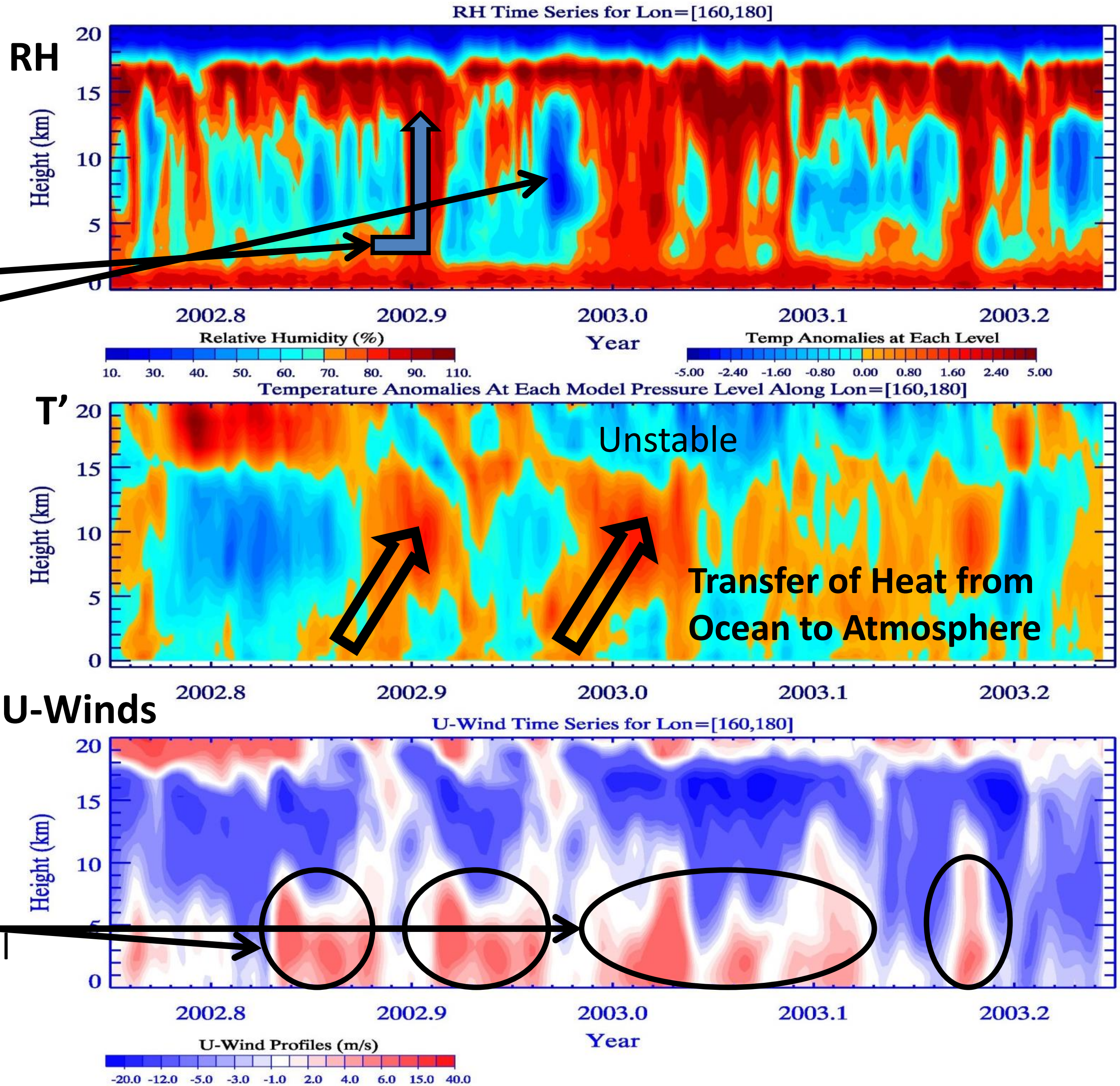
- While significant synoptic-to-submonthly variability exists of upward motion/ convection, more sustained and organized deep ascent follows hot spots
- Shallow to deep transition of convection with time

Convective Core Follows SST Hotspots with a fairly quick response time (days to weeks)



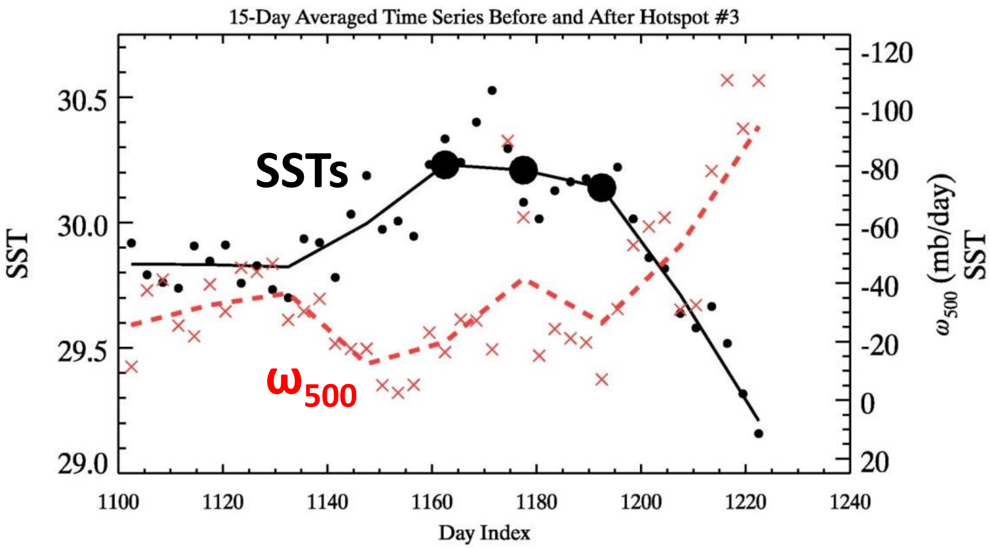
Zoomed in Vertical Profiles for Primary Hot Spot Region (2)

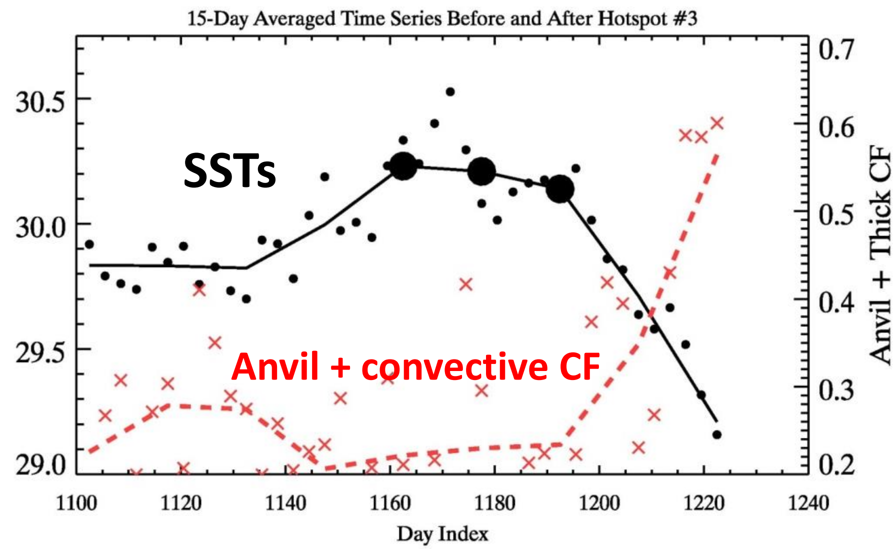
- Low-level moistening preceding deep convection, during/after hot spot peak
- Dry mid/upper troposphere (except near tropopause) prior to SST hot spots



Pulses of lower-level westerly winds in association with hot spots; they are associated with low-level convergence (not shown)

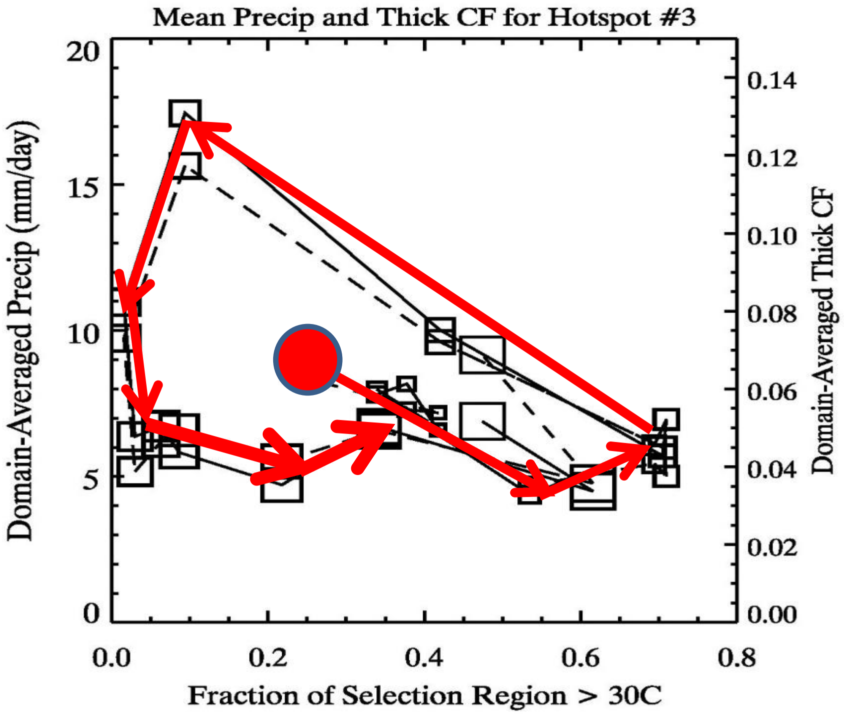
Feedbacks and "Predator-Prey" System of SSTs/Dynamics/Clouds





Top: Both strong ascent and anvil/convective core clouds increase strongly following hot spot event, with 15-30 day response time

Lower Right: Convective Core CF and Rain Rates follow a counterclockwise loop – after hot spot peak, convection utilizes, or "preys" on hot spots until hot spot is depleted, after which convection draws down and SSTs eventually rise again



Quick Summary

•Strong ascent, anvil and convective cloud fraction, and high rain rates are observed in the western and central South Pacific (0-10˚S) just after maximum SSTs associated with hot spots

•In some cases, the strength/duration of the hot spots coincides with the subsequent intensity of convection and precipitation

•Three independent datasets (MODIS, TRMM and ERA-Interim) are consistent with each other in illustrating these relationships, with anvil clouds and ω_{500} very strongly linked to each other, as well as convective core cloud fraction and rain rates

•Hot spots generally move east to west, except during El Nino, when hot spots are larger, more widespread, and longer-lasting

•The predator-prey relationship between SST and convection is an intuitive concept that illustrates the strongly coupled nature of ocean-atmosphere system