dSST/dt during wintertime (i.e., end of Feb. minus beginning of Dec, using 11-day averaged climatology)

Correlation between total precipitable water (from NVAP-M) and total cloud (from ISCCP). Using monthly data with climatology removed.
Cold Air Outbreaks and Warm Air Outbreaks at the Gulf Stream and the Agulhas Front

James F. Booth: City College of New York
Catherine M. Naud: NASA GISS & Columbia U.

MOTIVATING QUESTIONS

- How do clouds and moisture behave over the fronts in winter?
- Does the North American land mass impact this behavior at the Gulf Stream?
- What does a cold air outbreak look like in the SH?
During winter, high-cloud at Gulf Stream is directly above and north of front, rather than over warm water, i.e., clouds reflect atmosphere advection regime.

- **Minobe et al., 2010**

For poleward energy transport, we want to understand moisture and cloud behavior at front.

- Surface fluxes are big, especially LHF.

- Storms & SST Fronts coincide and storms have specific air types (next slide); this allows 1-to-1 relation between storm and surface-flux type.

- Rather than work from storms to SST, start with the surface fluxes, as in **Shaman et al. (2009)**. (Some of what I show echoes that work).
Light blue air mass corresponds to region of air in the **warm** conveyor belt.

Dark blue arrow corresponds to cold air. *Not the same as the cold conveyor belt.*
WHERE IS THE RAIN?

Solid cross-hatching: stratiform precipitation
Dashed cross-hatching: convective precipitation

COLD, DRY AIR
Plan: as in Naud et al. (2012); compare composites in NH and SH to derive information on time evolution of moist properties

**Known differences for frontal regions:**

1. SST warmer in Gulf Stream
2. Storm track more zonal at Agulhas Return Current
3. Land in NH (see Brayshaw et al. 2009, for land's large-scale impact)

**Datasets/Reanalyses**

- **Sea surface temperature (SST):** OISST merged dataset (Reynolds et al. 2007)
- **Surface Fluxes:** OAflux (Wu et al. 2008) and IFREMER (Bentamy et al.)
  
  \[ \text{flux} > 0 \] :: heat lost from ocean to atmosphere.

- **Temperature/Sea Level Pressure/Surface Winds:** ERA-Interim
- **Precipitable Water (PW):** NVAP-M (Van der Har et al., 2013)
- **Clouds:** MODIS (Ackerman et al. 2008)

- For each dataset, I use the daily data, from 2001-2009.
- **Cold seasons:**
  
  - NH: Nov. – Mar.
  - SH: May – Sep.

- The ANOMALIES defined with respect to mean created by calculating daily climatology and then smooth with 11-day filter.

**I also looked at 1999-2009, using ISCCP for clouds. Results are similar, but in SH there is a data gap in ISCCP.**
METHODS

Area-average the turbulent surfaces fluxes over GS and ARC
Repeat the analysis with SHF and LHF separately.

CAOs Cold Air Outbreaks :: strongest 10% of flux out of ocean.
WAOs Warm Air Outbreaks :: strongest 10% of flux into ocean.

Figures designed for comparison: cover the same lat/lon range.
Area avg. boxes are same size for SH and NH.
**Preliminary Study**

*flux dataset intercomparison: OAflux versus IFREMER*

Composites based on strongest events.
- Patterns match reasonably well.
- OAflux values are larger than IFREMER; true in composites.
- True in histograms of data at fronts.
- Similar agreement in patterns of warm air outbreaks as well (not shown).

**Do the two products capture the same extreme events?**

| Overlap of day of top 10% of surface flux events: +/- 1 day between OAflux and IFREMER |
|----------------------------------|-----------------|-----------------|
|                                  | Cold Air Outbreak | Warm Air Outbreak |
| total # events                  | 140              | 140              |
| NH                               | 90%              | 88%              |
| SH                               | 87%              | 80%              |
Dates of occurrence for strong** cold air outbreak (CAO) **top 10% of area-averages for flux from ocean

- GS max occurrence in CAO is in mid-winter.
- ARC max occurrence is early-winter.
- Differences in SHF and LHF distributions for GS discussed later.
COLD AIR OUTBREAKS (CAOs)

Surface: SST, yellow warm, blue cold.
Blue/Red lines: cold/warm fronts for extratropical cyclone.
METHODS (reminder)

Area-average the turbulent surfaces fluxes.

**CAOs** Cold Air Outbreaks :: strongest 10% out of ocean.

**WAOs** Warm Air Outbreaks :: strongest 10% into ocean.

- Composite atmospheric variables for the CAO, WAO
- Consider composites at time of flux and +/- 3 days
COLD AIR OUTBREAKS
Composites shown will all be based on strong LHF events.

RESULTS

GS LHF anomaly composite

ARC LHF anomaly composite

Time vs. area-averaged fluxes. Time=0 is shown in composite images

- As expected, composite on fluxes creates bull-eye on the fluxes.
- GS is markedly stronger than ARC, true of full flux value as well.
- No interesting results in time-series, though daily may limit this.
COLD AIR OUTBREAKS, BASED ON LHF

Tsurf anomaly stronger in NH. SLP anomaly suggests deeper storm
COLD AIR OUTBREAKS, BASED ON LHF

- Wind composites show similar strength in GS and ARC.
- Stronger anomalies over warm sector, consistent with Booth et al. 2010.
- Time-series show build-up of winds, strong drop in SLP, Tsurf.

**GS sfcWind anomaly composite**

**ARC sfcWind anomaly composite**
COLD AIR OUTBREAKS, BASED ON LHF

- Inverse relationship: negative (i.e. dry) anomalies over warm side of fronts correspond to positive cloud anomalies.
- Near the fronts, only the cold side of ARC show positive relationship.
Cold air outbreak composite results:

- Strength of CAO at GS much stronger than ARC.

- Synoptic patterns suggest:
  - CAO occur in wake of synoptic storms (as in Shaman et al. 2009)
  - GS has colder temperature anomalies and larger storm.
  - sfcWinds do not show a marked difference at GS and ARC.

Synthesis: North American land mass is preconditioning air, to help generate stronger fluxes. Otherwise, CAO in ARC look very much like CAO at Gulf Stream.

- Moist variables:
  - Over warm sector, there is inverse relationship between moisture and cloud fraction.

Synthesis: results show two things: (1) simple reminder that clouds care about relative humidity (RH), not precipitable water (PW), and (2) cloud fraction can be tricky to interpret, because there is no depth in the metric.
Comparing date of occurrence for the top 10% events based in SHF and LHF

- In SH and NH, strong overlap for CAOs: ~75%
- In SH, warm air outbreaks show weakest agreement.

<table>
<thead>
<tr>
<th></th>
<th>Cold Air Outbreak</th>
<th>Warm Air Outbreak</th>
</tr>
</thead>
<tbody>
<tr>
<td>total # events</td>
<td>140</td>
<td>140</td>
</tr>
<tr>
<td>NH</td>
<td>0.72</td>
<td>0.64</td>
</tr>
<tr>
<td>SH</td>
<td>0.77</td>
<td>0.48</td>
</tr>
</tbody>
</table>

FOR GS: strong LHF but not SHF more likely in early winter.
WARM AIR OUTBREAKS (WAO)S
NH (above) & SH (below)

Surface: SST, yellow is warm, blue is cold.
Blue and Red lines: cold and warm fronts for extratropical cyclone.
Red arrow: warm air sector within the cyclone.
**Warm Air Outbreaks (WAOs):**

- Strongest 10% of area-averaged flux into the ocean.

**Composites:**

- GS SHF anomaly composite
- ARC SHF anomaly composite

- Composites shown will all be based on strong SHF events.
- As expected, composites of SHF anomalies show a bulls-eye.
- Once again, GS has much stronger amplitude than ARC.
- Temperature anomaly is much stronger over the GS as compared to the ARC.
- SLP in GS shows very weak low pressure anomaly, i.e., storm is developing.
- SLP in ARC shows a strong low pressure anomaly, suggesting more developed storm.
WARM AIR OUTBREAKS, BASED ON SHF

- Winds are a mess. At GS, weak negative anomaly or no signal. At ARC, positive wind anomaly is in agreement with SLP anomaly and reflects the storm being developed.
- Time-series for GS and ARC differ slightly, with timing in ARC accelerated.
- Again, over warm sector of ocean frontal region, water vapor and clouds show inverse relationship.
- Over cold sector, positive relationship exists.
In both hemispheres, strong SHF-into-ocean events without accompany by strong LHF occur in early winter and strong LHF-into-ocean events without strong SHF events occur in late winter. (i.e., in late winter, during these events, moisture alone is robbed from the storms.)
DISCUSSION

N. America has expected influence in strongest flux events: preconditioning air within cold air outbreaks.

Otherwise, CAO and WAO for GS and ARC differ because:
- GS is storm track entrance

ARC storm track being more zonal is not as evident in these composite.

Asymmetry in PW and cloud anomalies reflect role of RH and local moisture source at warm side of fronts.

NEXT:
- Use satellite winds.
- Examine precipitation.

THANK YOU