Identifying stratospheric air intrusions and associated hurricane-force wind events over the north Pacific Ocean

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BACKGROUND

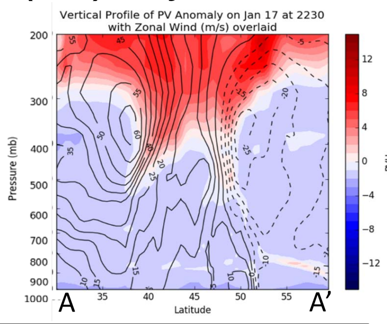
Motivation

- Ocean data is sparse
  - Reliance on satellite imagery for marine forecasting
- Ocean Prediction Center (OPC) – "mariner's weather lifeline"
  - Responsible for:
    - Pacific, Atlantic, Pacific Alaska surface analyses/forecasts – 24, 48, 96 hr
    - Wind & wave analyses/forecasts – 24, 48, 96 hr
    - Warning Services & Decision Support
- Geostationary Operational Environmental Satellite – R Series (now GOES-16)[4] comparable to Japanese Meteorological Agency's Himawari-8

Stratospheric Air Intrusions

AKA: tropopause folds, stratosphere-troposphere exchange (STE), dry intrusion

- Exchanges of air between stratosphere and troposphere
  - Differences in humidity, ozone levels, and potential vorticity
- Importance to weather systems[1,3]
  - +PV anomaly changes vertical distribution of potential temperature & vorticity
  - Promotes rapid cyclogenesis (see right)



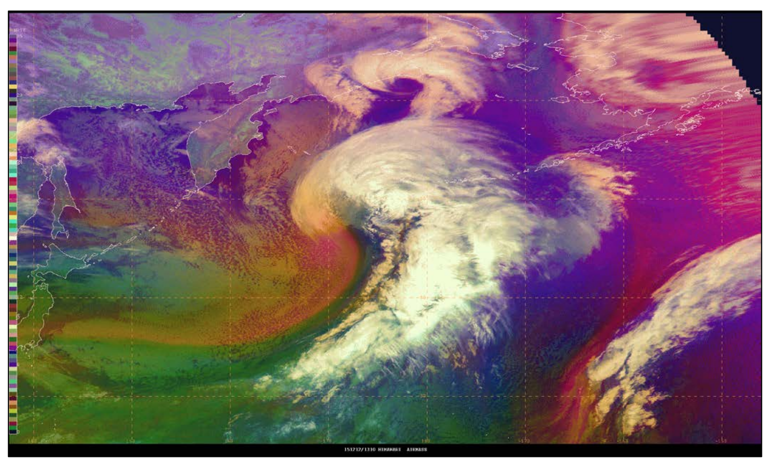
Research Question: How can integrating satellite data imagery and derived products help forecasters improve prognosis of rapid cyclogenesis and hurricane-force wind events?
Phase I – Identifying stratospheric air intrusions

DATA & METHODS

Himawari-8 Airmass RGB

- Each color band represents a wavelength (difference)
- Different wavelengths capture different layers of atmosphere

Red	6.2 µm minus 7.3 µm, representing moisture between 300-700 mb
Green	9.6 µm minus 10.3 µm, representing thermal response & tropopause height
Blue	6.2 µm inverted, representing moisture between 200-400 mb



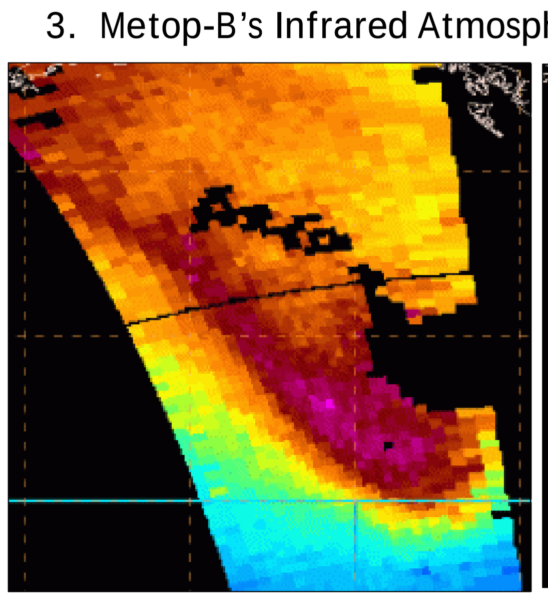
Courtesy of NOAA/NCEP/OPC

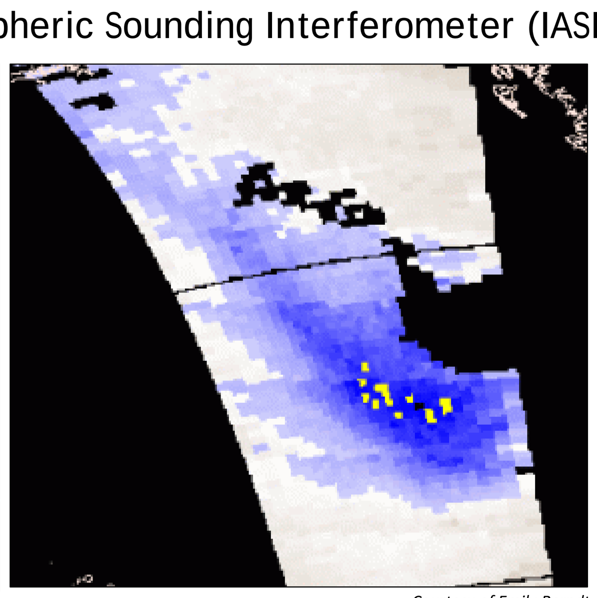
Common color interpretations (Zavodsky et al., 2013):

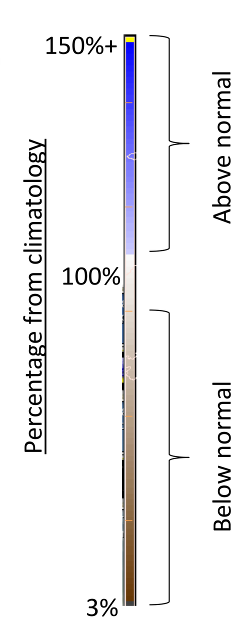
Jet/high PV	Moist Upper Trop.
Thick, high cloud	Thick, mid-level cloud
Dry Upper Trop.	Cold air mass

Total Column Ozone & Ozone Anomaly

- Used to help quantify Airmass RGB
- Examples of instruments:
  1. Aqua's Atmospheric Infrared Sounder (AIRS)
  2. S-NPP's Cross-track Infrared Sounder/Advanced Technology Microwave Sounder (CrIS/ATMS)
  3. Metop-B's Infrared Atmospheric Sounding Interferometer (IASI)



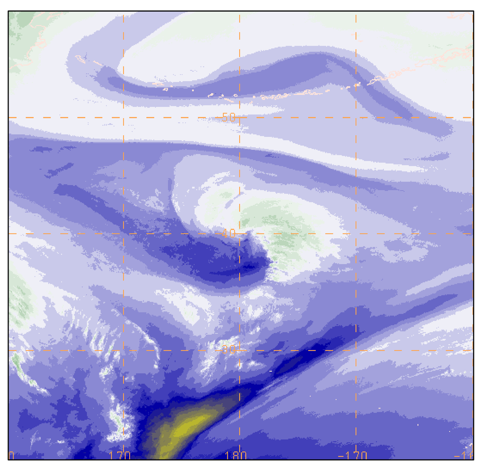


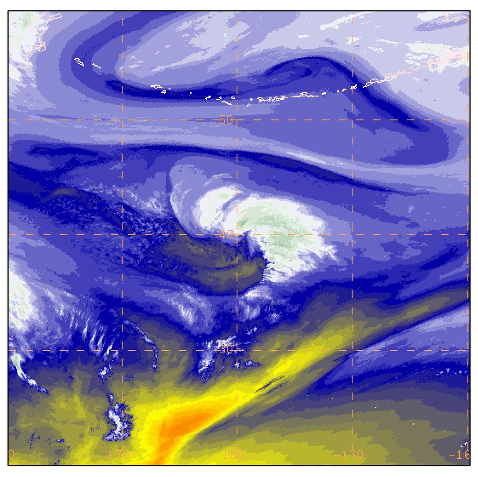


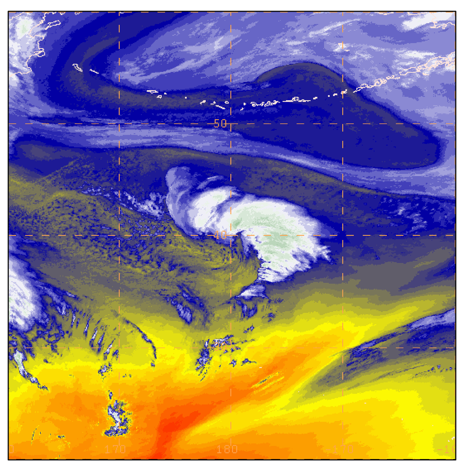
Courtesy of Emily Berndt

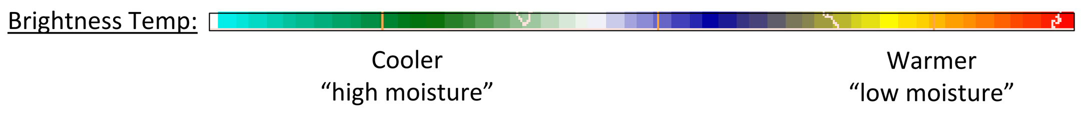
Himawari-8 Water Vapor

Upper-layer	Middle-layer	Lower-layer
6.2 µm channel	6.9 µm channel	7.3 µm channel
Peak response at ~350 mb	Peak response at ~450 mb	Peak response at ~650 mb









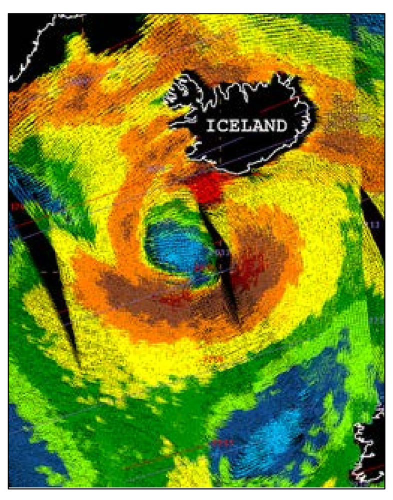
Scatterometer & Microwave Radiometer

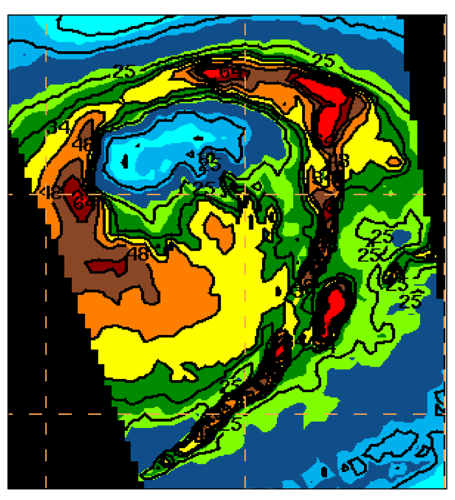
Scatterometer
- Used to verify hurricane-force
- Measures backscatter of radar signal for wind speed & direction

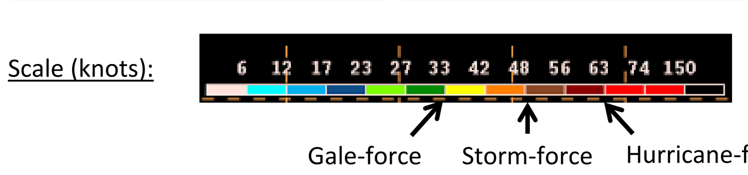
e.g. Advanced SCATterometer (A/B)

Microwave Radiometer
- Measures microwave signal response for only wind speed

e.g. Advanced Microwave Scanning Radiometer (AMSR-2)







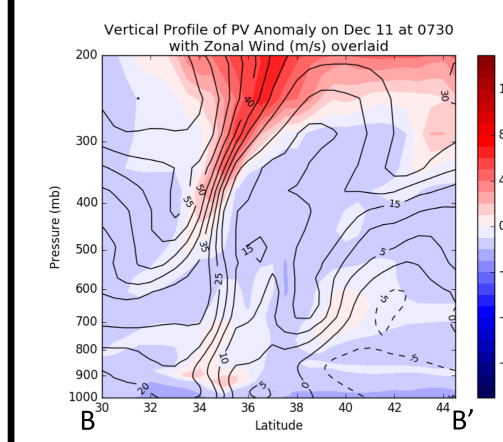
CASE STUDY ANALYSES

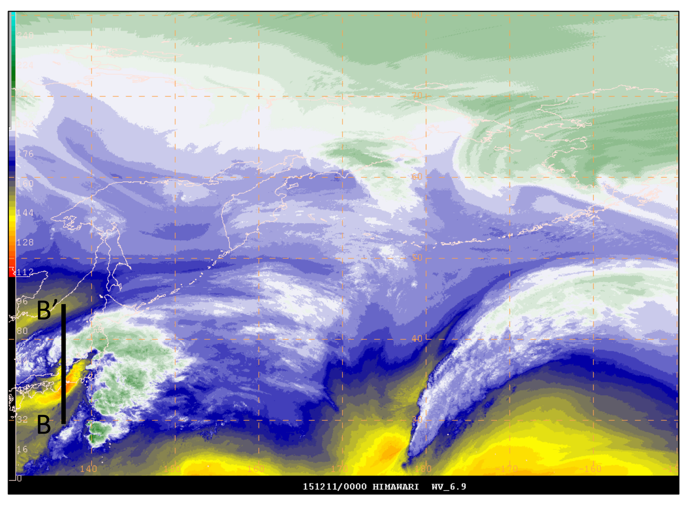
Case Studies:

- Represent a wide variety of extratropical storm types

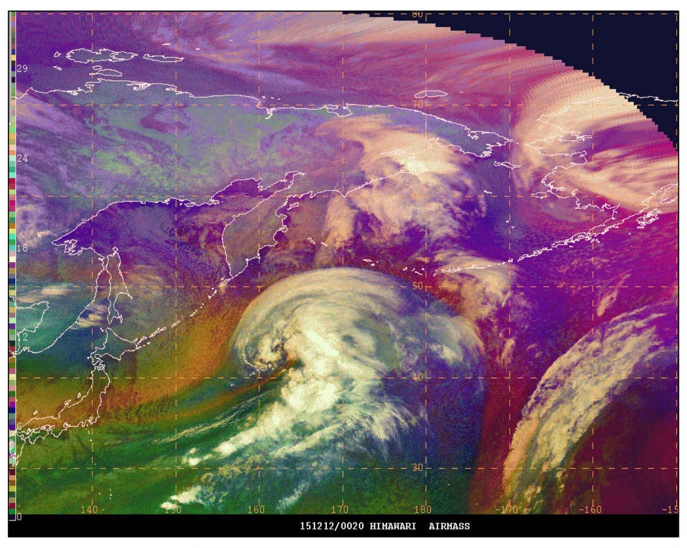
Name	Date Range	Reasons for Interest
Bering Sea Bomb	December 11-13, 2015	• One of the strongest (924 mb center) non-tropical storms on record • Large impacts
Winter Underdog	January 17-19, 2016	• Developed rapidly despite small size • Hard to distinguish early features
Spring Transition	April 7-9, 2016	• Late season cyclone • Atypical development
TC Songda Transition	October 12-15, 2016	• Lost most of its tropical features • Atypical extratropical transition & development

Bering Sea Bomb:

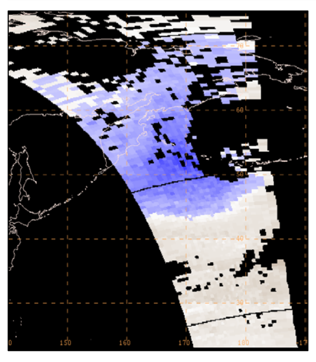


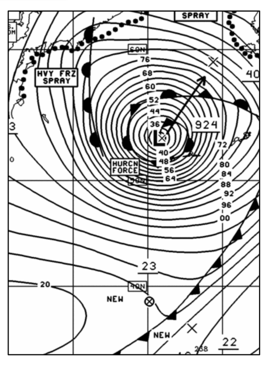


1. Early feature
- Deep tropopause fold



2. Rapid Development
- Polar front with high-PV air approaching
- Baroclinic leaf in its cloud head
- Multiple vortices in cloud head

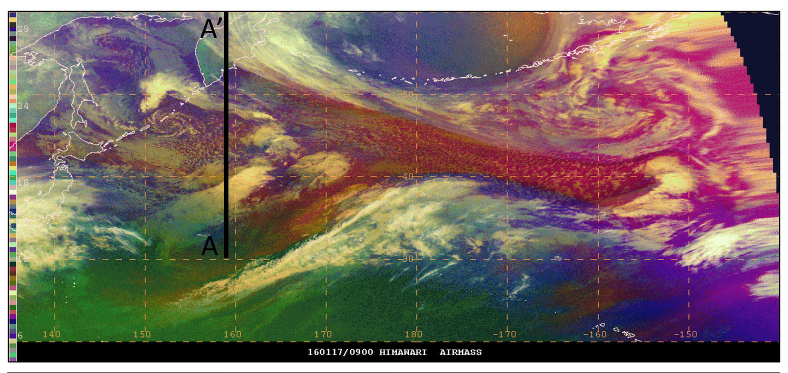




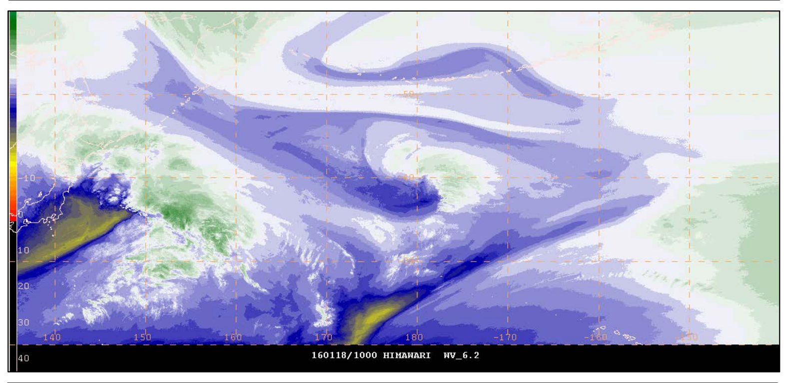
3. Peak Intensity
- Cold, high-PV air gets wrapped into system
- Dec 13: 924-mb central pressure
- Expansive in size

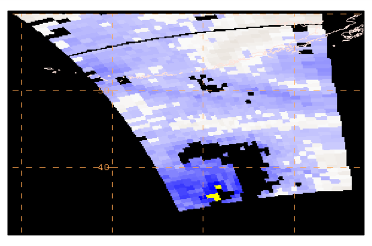
Winter Underdog:

1. Early features
- PV streamer
- Baroclinic leaf supplying latent heat
- Piece of vorticity absorbed by streamer



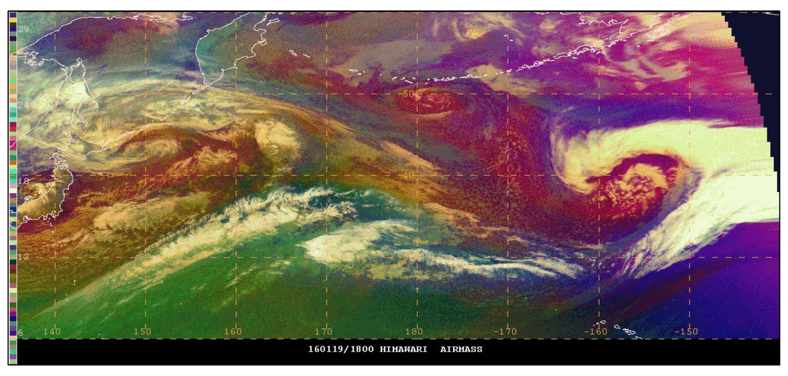
2. Rapid Development
- Small comma cloud that gets brighter
- Vortex lobe north of system that threatens, eventually intersecting with original streamer



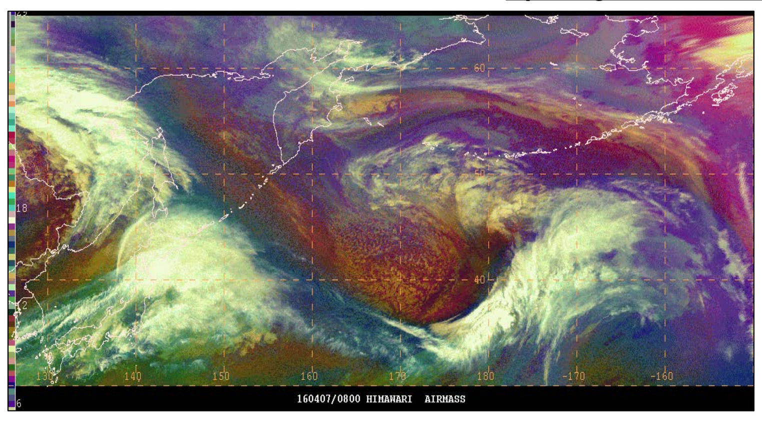


- Anomalous ozone more condensed
- AIRS suggesting 150%+ climatology!

3. Peak Intensity
- S-K cyclone model features
- Possible warm seclusion in low's center

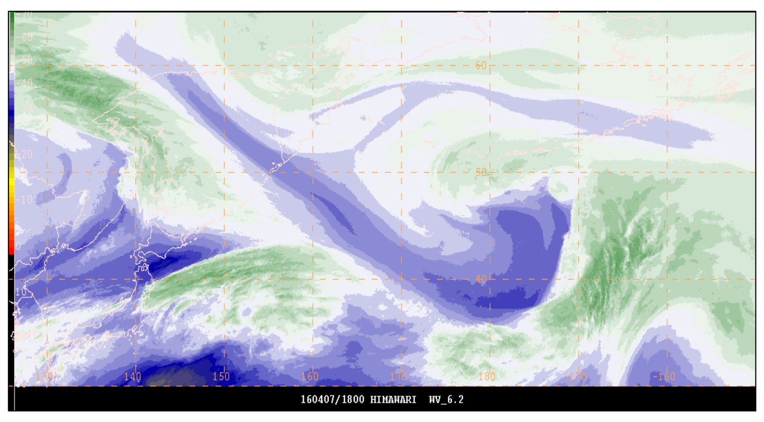


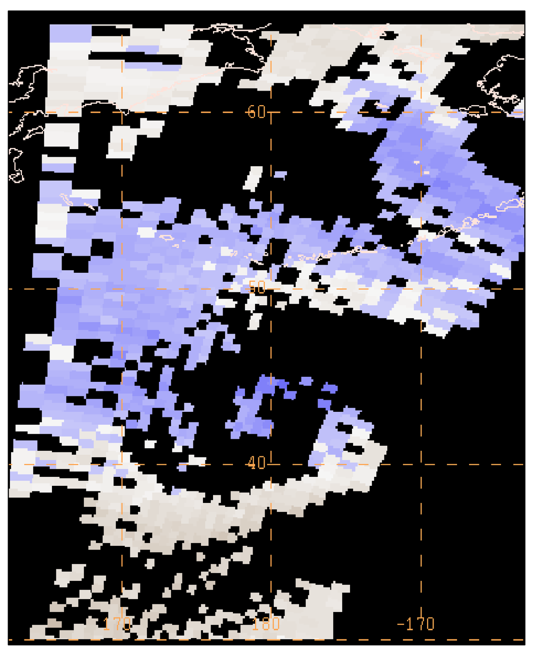
Spring Transition:

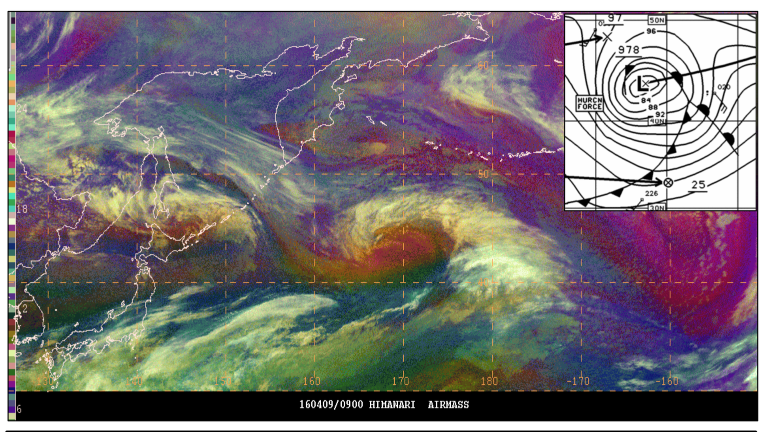


1. Early features
- Dry streamer
- Shortwave
- Baroclinic leaf seen with cloud development
- Wind shear/jet streak?
- Mature storm north of it

2. Rapid Development
- Diffluence & splitting streamers
- Tropopause fold
- Vortex lobe
- Trough amplification downstream



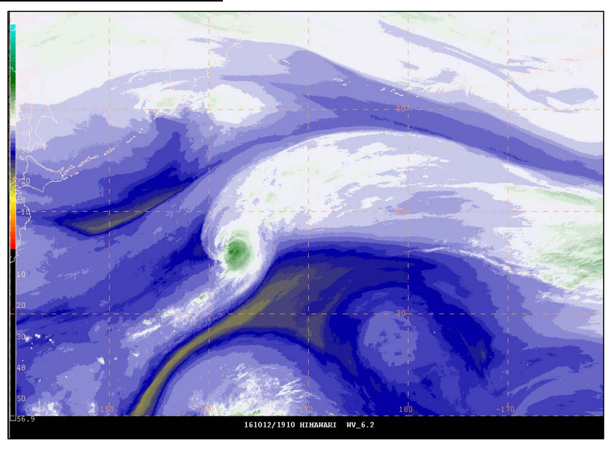




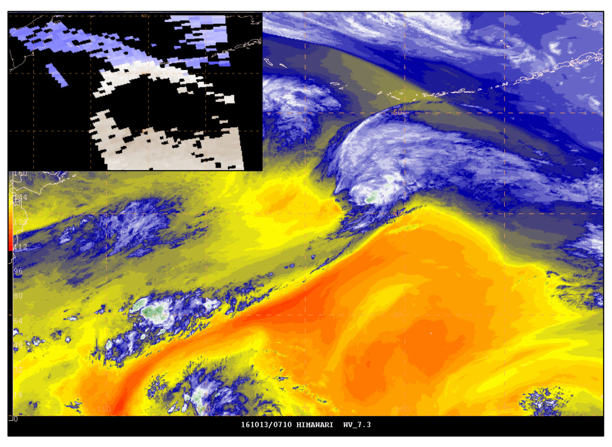
3. Peak Intensity
- Sharp dry-moist gradient with front
- "Bowling Ball" → getting cutoff from large-scale flow

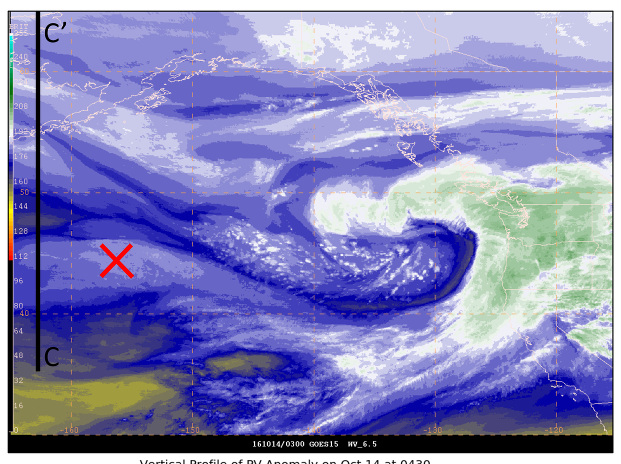
Songda Transition:

1. Early features
- Shortwave
- Dry air juxtaposed on western side of hurricane (strat. air?)
- Region of high ozone/PV northward
- Baroclinic leaf

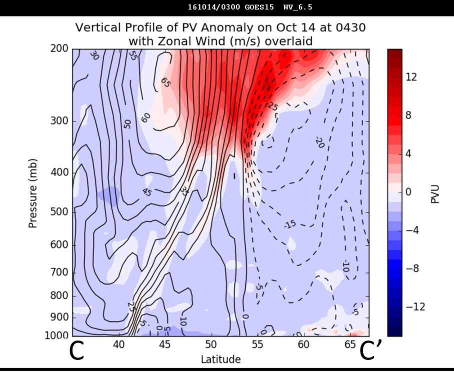


2. Rapid Transition
- Shortwave w/ drying to low levels
- Losing tropical structure (eye, less 'cold' WV signal)
- Entering region of higher PV

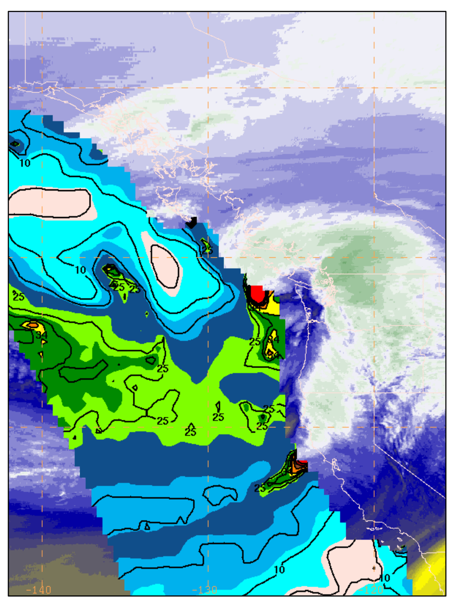




3. Rapid Re-development
- Deep intrusion west of remnants (labeled 'X')
- Vortex lobe north
- Upper-level pattern favored intensification



4. Peak Intensity
- Impacts western US coast on 15 Oct ~2100 UTC
- Transition & re-development takes less than 48 hours



CONCLUSION

Summary

- Stratospheric air intrusions → +PV → Explosive cyclogenesis → Hurricane-force winds
- Single Water Vapor channels supply forecasters with information about jet stream interactions and tropopause folds
  - Can only look at single layer of atmosphere at a time
  - Doesn't give info about if air is from stratosphere
- Potential in Airmass RGB + ozone products to identify stratospheric air intrusions
- Other features seen in imagery & products proved to be instrumental in storm's development to hurricane-force winds:
  - Shortwaves (trough-like kinks in Rossby wave)
  - Latent heat release upstream (baroclinic leaf structures)
  - Nearby mid-level circulations, vortex lobes, etc. (sources of vorticity)
  - Boundaries (e.g. polar fronts)

Future Work

- Look at other cases with GOES-16
- Phase II- Look at other cases in North Atlantic Ocean (GOES, SEVIRI)
- Phase III- Build instructional toolkit for OPC & Alaskan WFO forecasters
  - More real-time use
  - Training for RGB Airmass and ozone products as supplementary information about intrusions

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