Comparing momentum flux of mesospheric gravity waves using different background measurements and their impact on the background wind field

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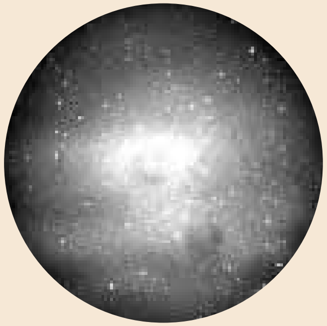
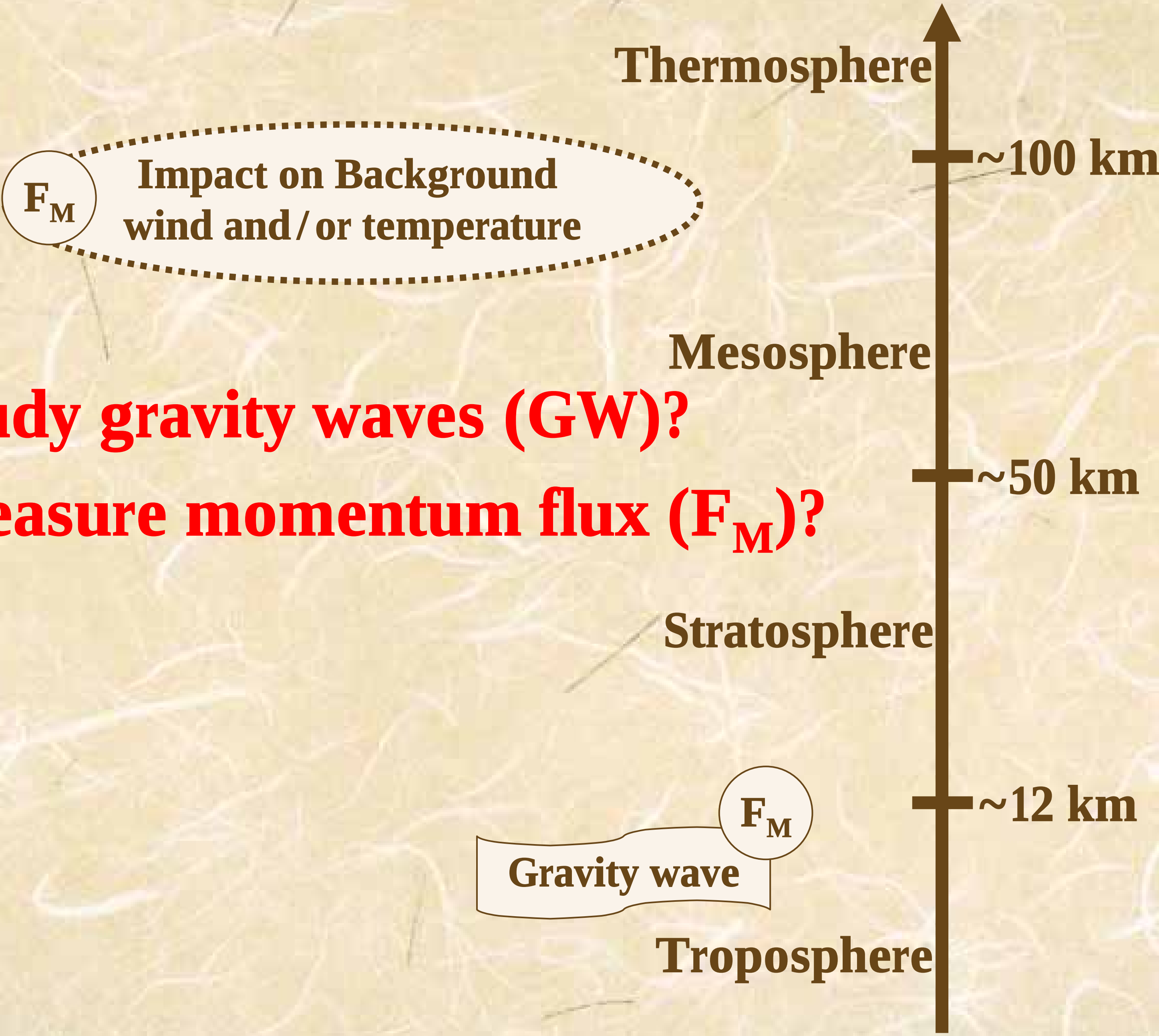
Outline

- **Introduction**
- **Instrumentation at Maui-MALT, Hawaii**
  - **Mesospheric Temperature Mapper (MTM)**
  - **Na Wind/Temperature Lidar**
  - **Meteor Wind Radar**
- **Case study 1:**

  Radar vs. Lidar for Momentum Flux Studies
- **Case study 2:**

  Gravity Wave-Critical Level Interaction
- **Conclusions**





Thermosphere

~100 km

F_M Impact on Background wind and / or temperature

Mesosphere

- **Why study gravity waves (GW)?**
- **Why measure momentum flux (F_M)?**

~50 km

Stratosphere

~12 km

F_M Gravity wave

Troposphere

Momentum Flux Calculations for Quasi-Monochromatic Events

k: horizontal wave number
c: horizontal phase speed
I: Intensity

- **Momentum Flux (F_M) equations:**
  - $$F_M = \frac{k}{m} \cdot \frac{g^2}{N^2 \cdot CF^2} \cdot \left(\frac{I'}{\bar{I}} \right)^2$$ **----- (1) assumption of "$\lambda_h >> \lambda_z$"**
    [Swenson and Liu, 1998]
  - $$F_M = \frac{k \cdot m}{\left(k^2 + m^2\right)} \cdot \frac{g^2}{N^2 \cdot CF^2} \cdot \left(\frac{I'}{\bar{I}} \right)^2$$ **----- (2) assumption of "$\lambda_h \sim \lambda_z$"**

$$\left\{ \begin{aligned} m^2 &= \frac{N^2}{(c-u)^2} - k^2 - \frac{1}{4 \cdot H^2} \\ N^2 &= \frac{g}{T} \cdot \left(\frac{dT}{dz} - \frac{g}{C_p} \right) \sim 4.0 \times 10^{-4} \text{ [rad/sec]} \\ H &= {RT}/{g} \sim 6.0 \text{ [km]} \end{aligned} \right.$$

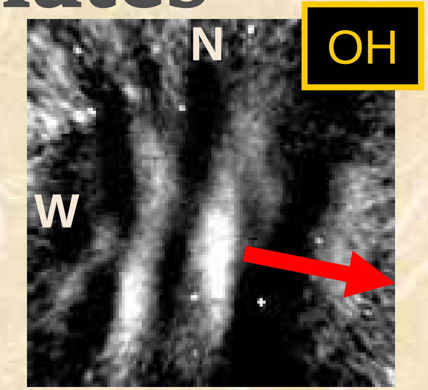
m: vertical wave number
u: background wind
T: background temperature
N: Brunt-Väisälä frequency
H: scale height
g: gravity acceleration
CF: Cancellation factor
C_p: adiabatic laps rate

Qu: What quality background data are needed for F_M?

Plan

- We compare results of F_M (for GWs observed by the MTM) calculated using:
  - Na wind/temperature lidar data (exhibiting high time and vertical resolution)
  - meteor wind radar (with lower resolution as compared to Na lidar but constant operation)
  - We investigate the advantages of each method for F_M estimations.
- Using a case study of GW dissipation associated with wind filtering at a critical level, we quantify the impact from the GW on the background wind field.

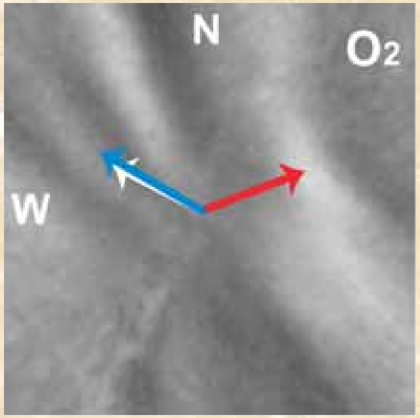
Case Study 1: Radar vs. Lidar for Event Momentum Flux Estimates

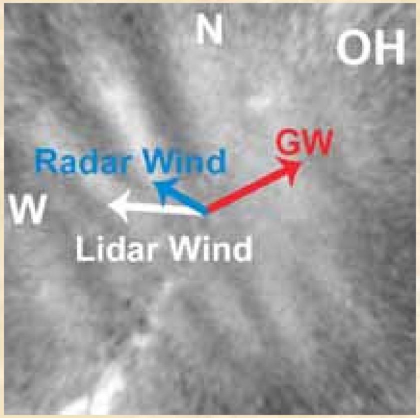


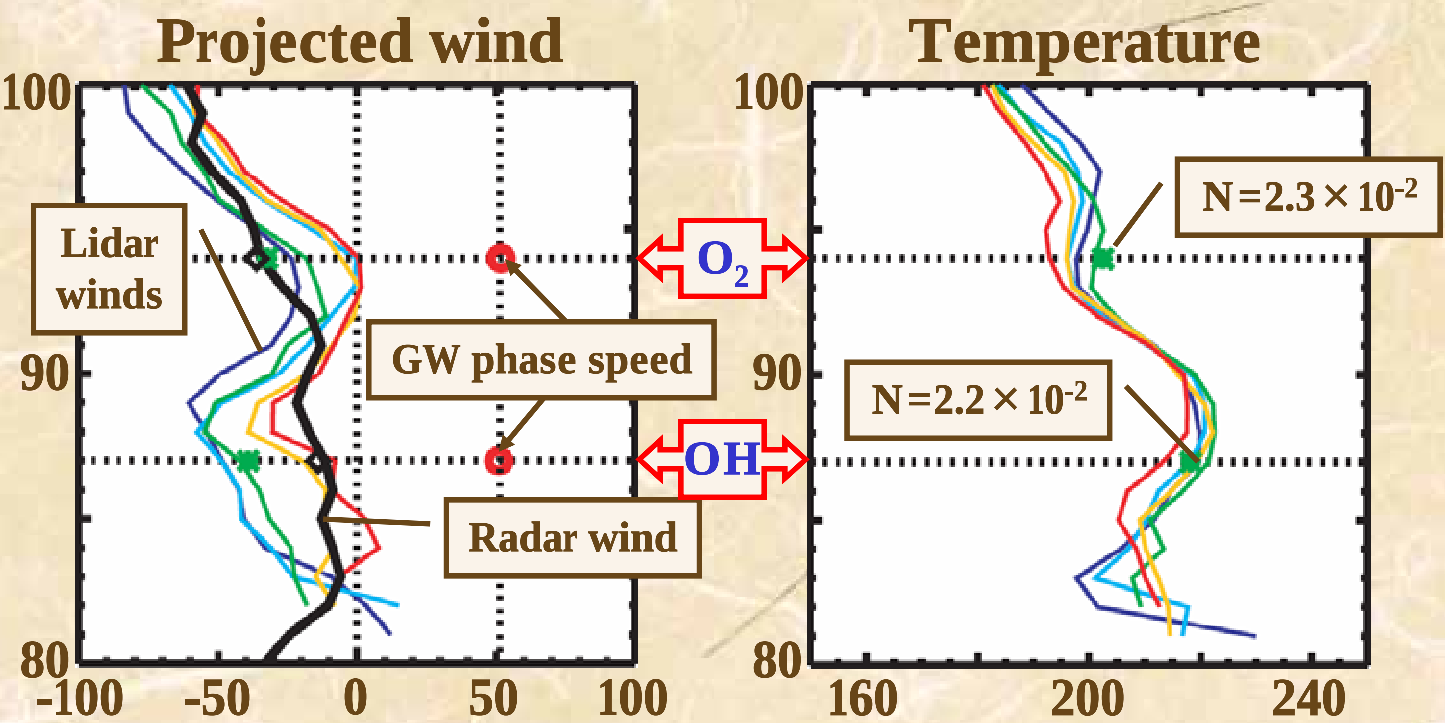
- **Station**
  - **Maui-AEOS Facility - Hawaii (20.8°N, 156°W)**
- **Data**
  - **Mesospheric Temperature Mapper (MTM)**
    → *GW propagation parameters, intensity perturbations*
  - **Na Wind/Temperature Lidar** → *Background wind and temperature*
  - **Meteor Wind Radar** → *Background wind*
- **Simultaneous Observations**
  - **4 events (2 nights)**

Date	UT	Emission	λ_h [km]	c [m/s]	Period [min]	Direction [º]	DI/I
Jul. 9, 2002	11:30	OH	35.5	51	11.6	63.7	9.5
		O_2	52.8	51.8	17.0	69.4	12
	14:30	OH	41.3	44	15.6	99.8	12.5
		O_2	42	46.8	15.0	100	8.9
Aug. 12, 2004	7:30	OH	26.9	38.3	11.7	57.9	5.3
		O_2	-----	-----	-----	-----	-----
	13:00	OH	22.1	26.9	13.7	103.7	3.6
		O_2	23.9	25.3	15.7	105.5	3.7

Event #1: July 9, 2002, 11:30 UT





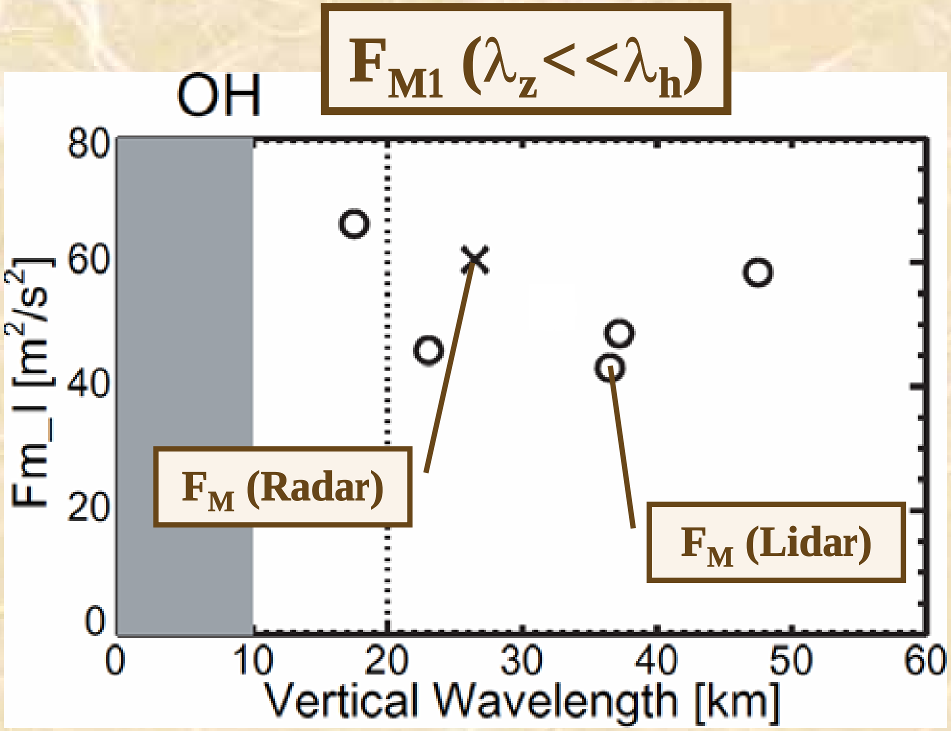


Wave parameters

- λ_h ~40 km
- c ~50 m/s
- I'/I ~10%

- $F_{M1} = \frac{k}{m}\cdot\frac{g^2}{N^2\cdot CF^2}\cdot\left(\frac{I'}{\bar{I}}\right)^2$ ----- "$\lambda_h >> \lambda_z$" [Swenson and Liu, 1998]
- $F_{M2} = \frac{k\cdot m}{\left(k^2+m^2\right)}\cdot\frac{g^2}{N^2\cdot CF^2}\cdot\left(\frac{I'}{\bar{I}}\right)^2$ ----- "$\lambda_h \sim \lambda_z$"

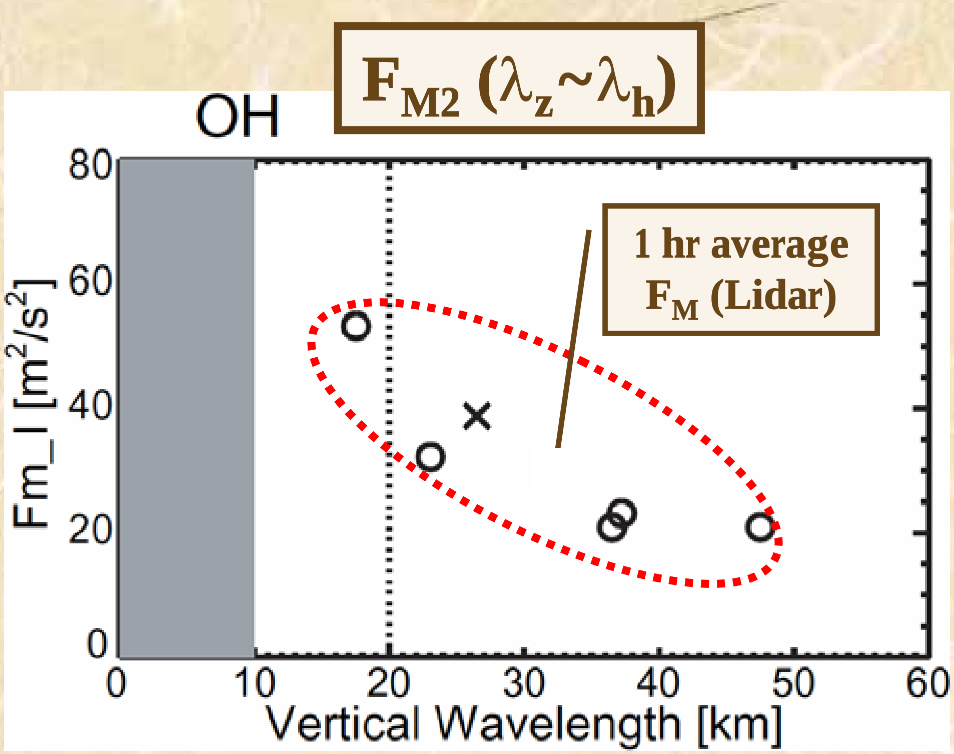
F_M Results (Event #1)



F_{M1} ($\lambda_z << \lambda_h$)

F_M (Radar)

F_M (Lidar)



F_{M2} ($\lambda_z \sim \lambda_h$)

1 hr average F_M (Lidar)

$F_{M1} \sim 40\text{-}70\ m^2/s^2$

$F_{M2} \sim 20\text{-}50\ m^2/s^2$

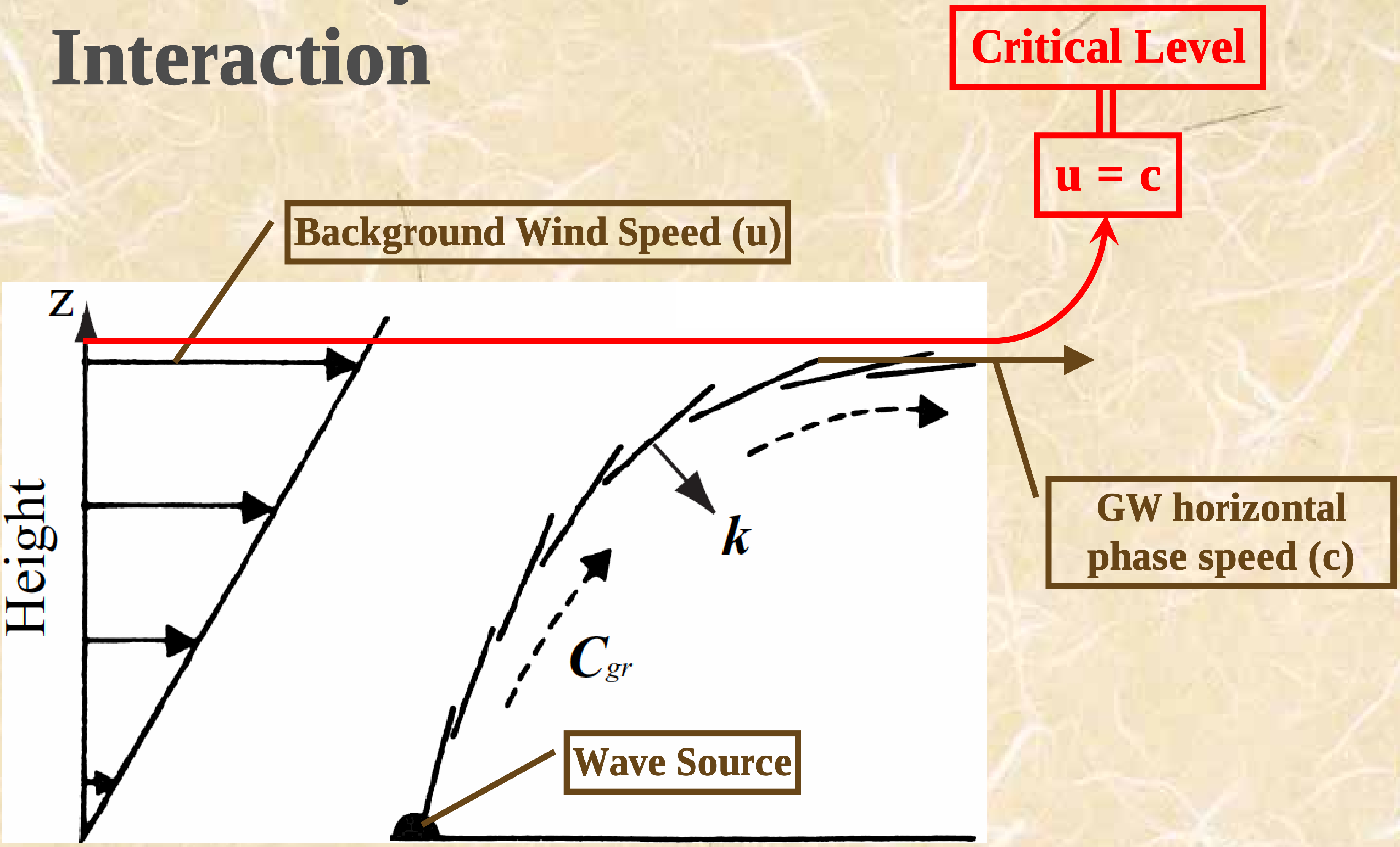
- **F_M(Radar) ≈ 1 hr average F_M(Lidar)**

Conclusion 1

- F_M calculated using revised assumption ($\lambda_z \sim \lambda_h$) gives significant lower values (> ~30%) than method used in previous studies ($\lambda_z << \lambda_h$).
- Background wind profiles are more critical for estimating vertical wavelength and F_M than background temperature data.
- F_M (radar wind) ~ 1 hr average F_M (Na lidar wind & temp.)
- Thus:

  Under typical mesospheric conditions, Meteor Radar wind data (combined with constant N value) produces reasonable estimates of the wave event F_M for long-term studies.

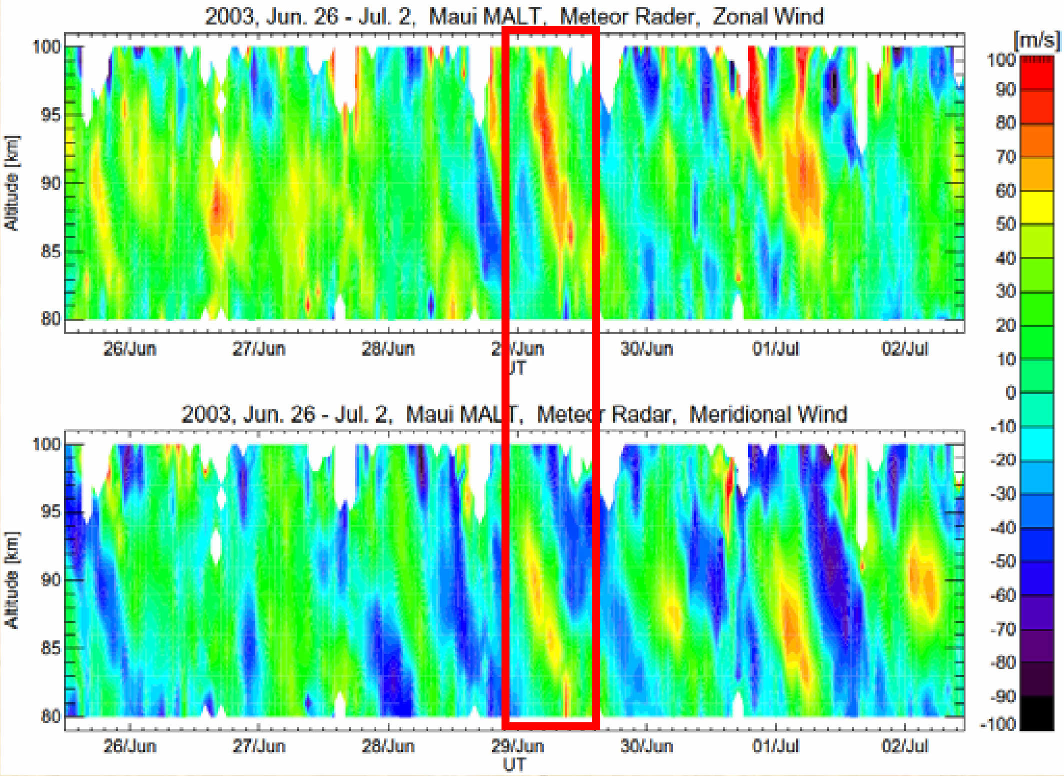
Case Study 2: GW-Critical Level Interaction



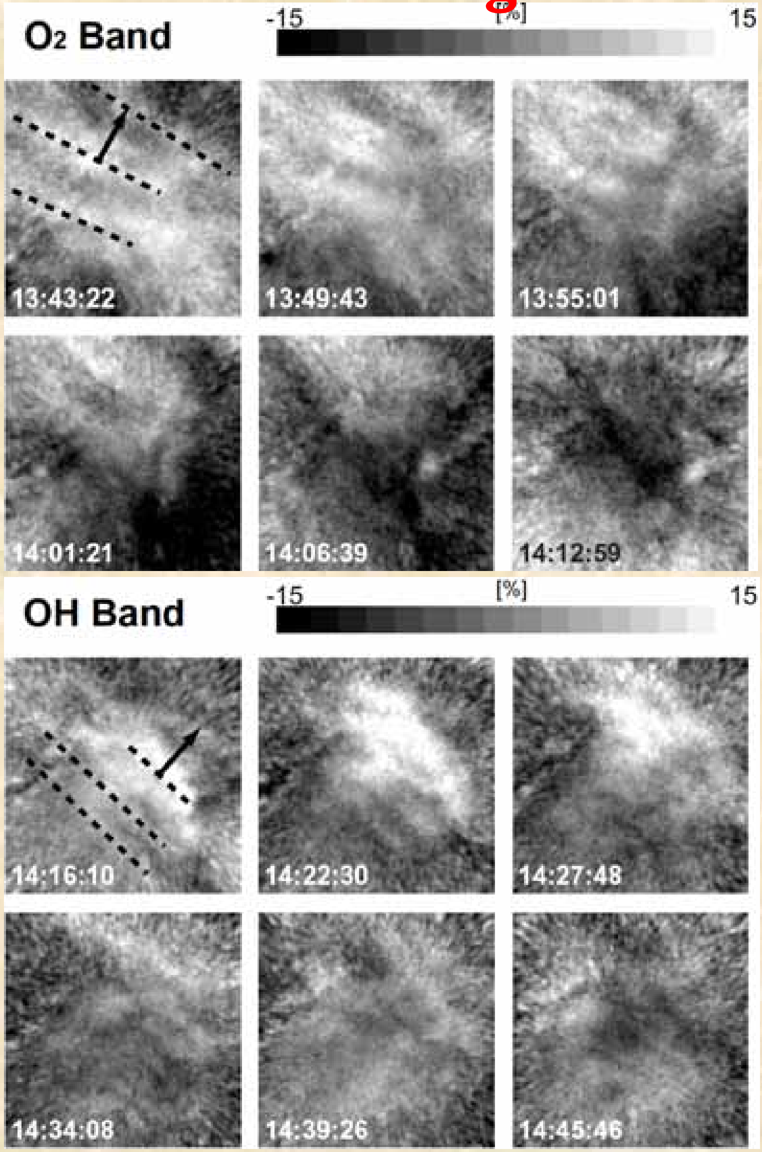
Qu: What happens to a GW at a Critical Level?

Ex. of GW-CL Interaction (June 29, 2003)

Meteor Radar Winds



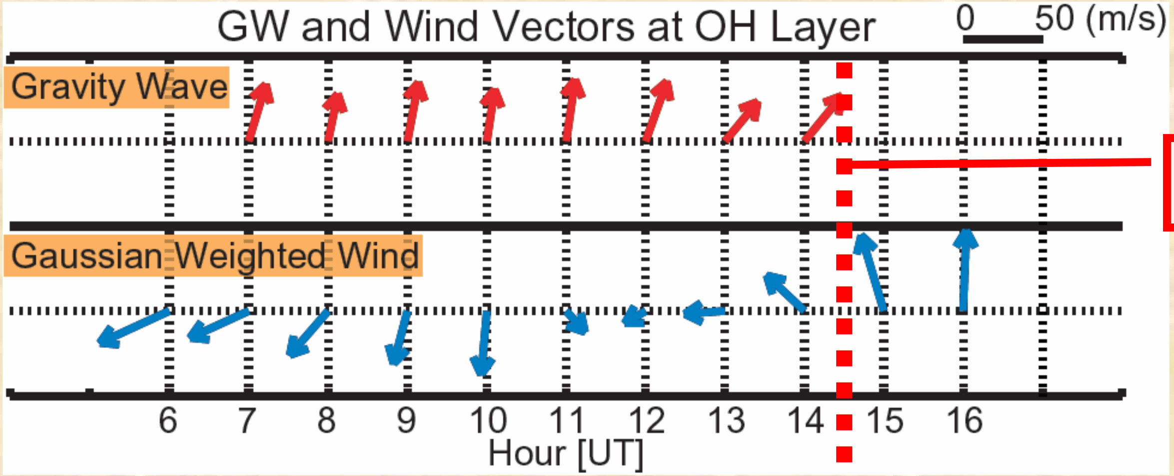
MTM Images



- **Observations:**
  - **Strong Diurnal-Tide**
  - **GW dissipation at O_2**
  - **GW dissipation at OH**

Cause of Wave Disappearance?

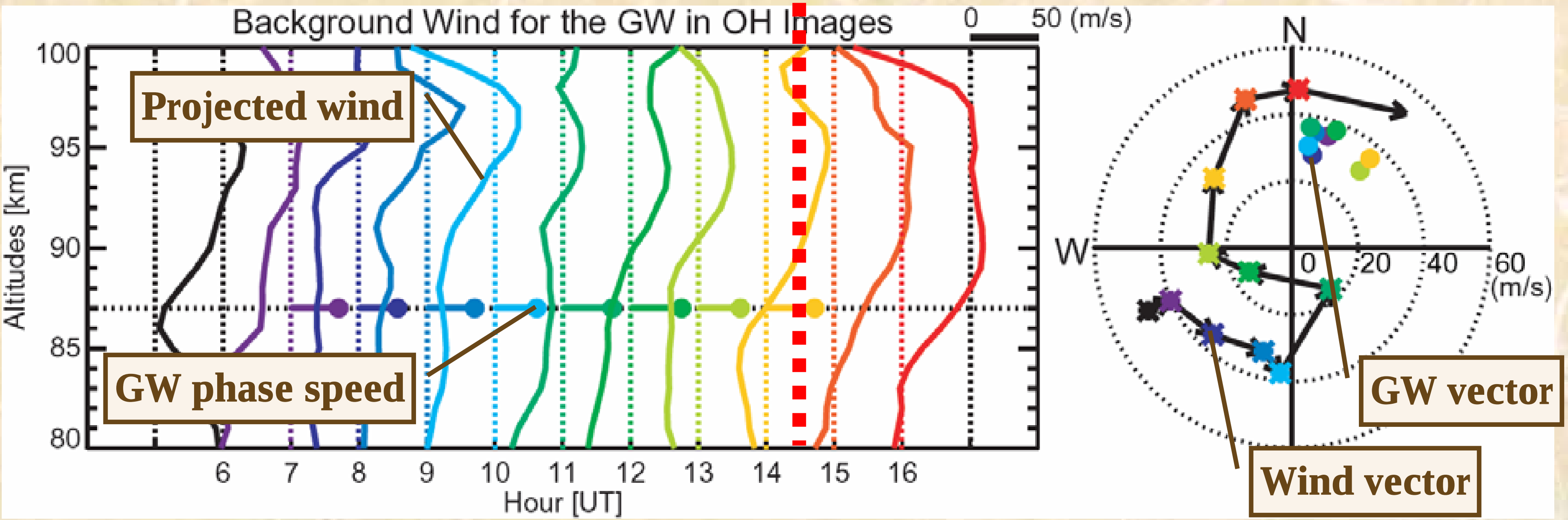
OH



GW-CL interaction

↓

Wave dissipation



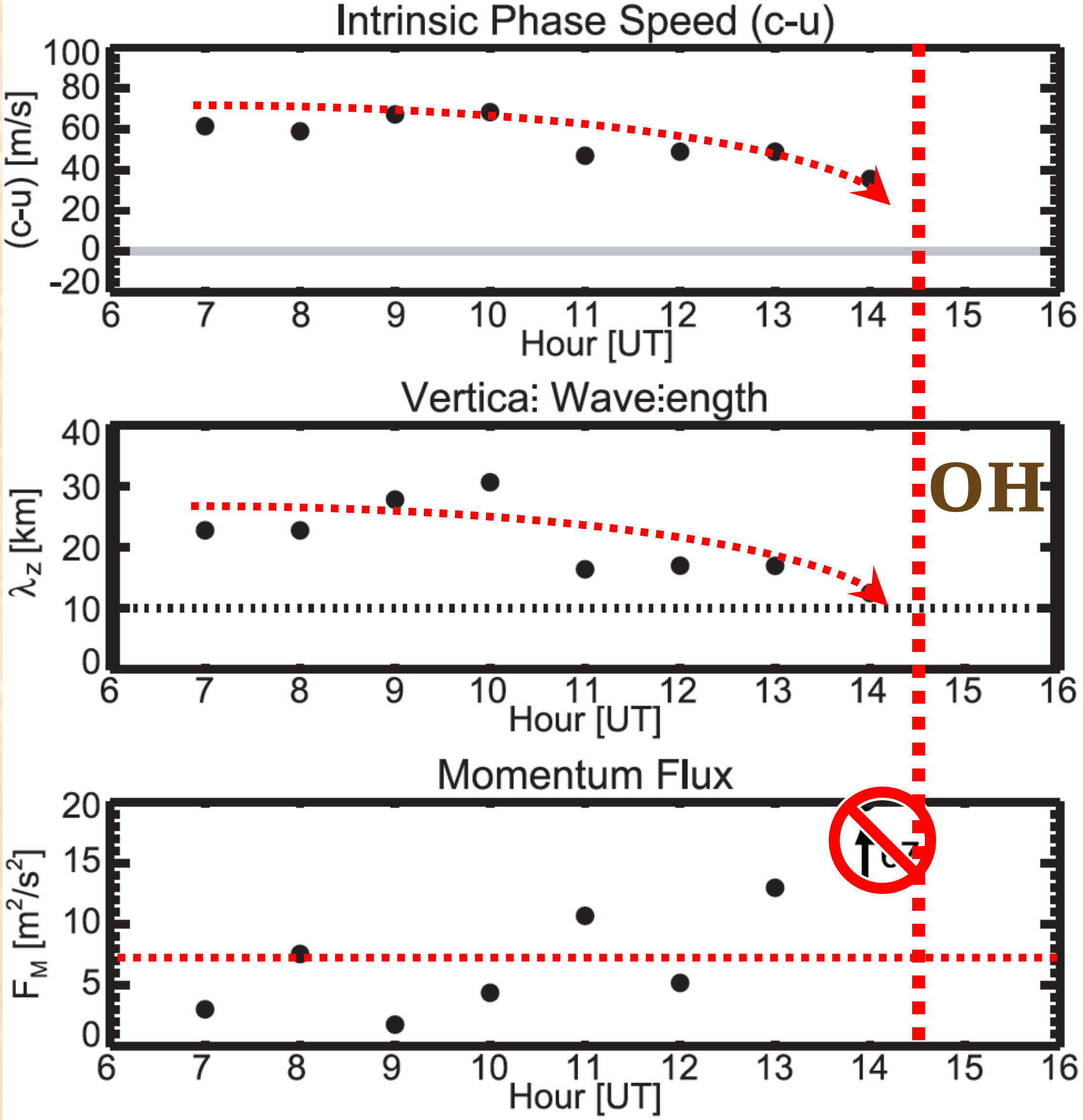
Projected wind

GW phase speed

GW vector

Wind vector

Effect of Critical Level on GW Parameters and F_M



Intrinsic phase speed

↓

decreases

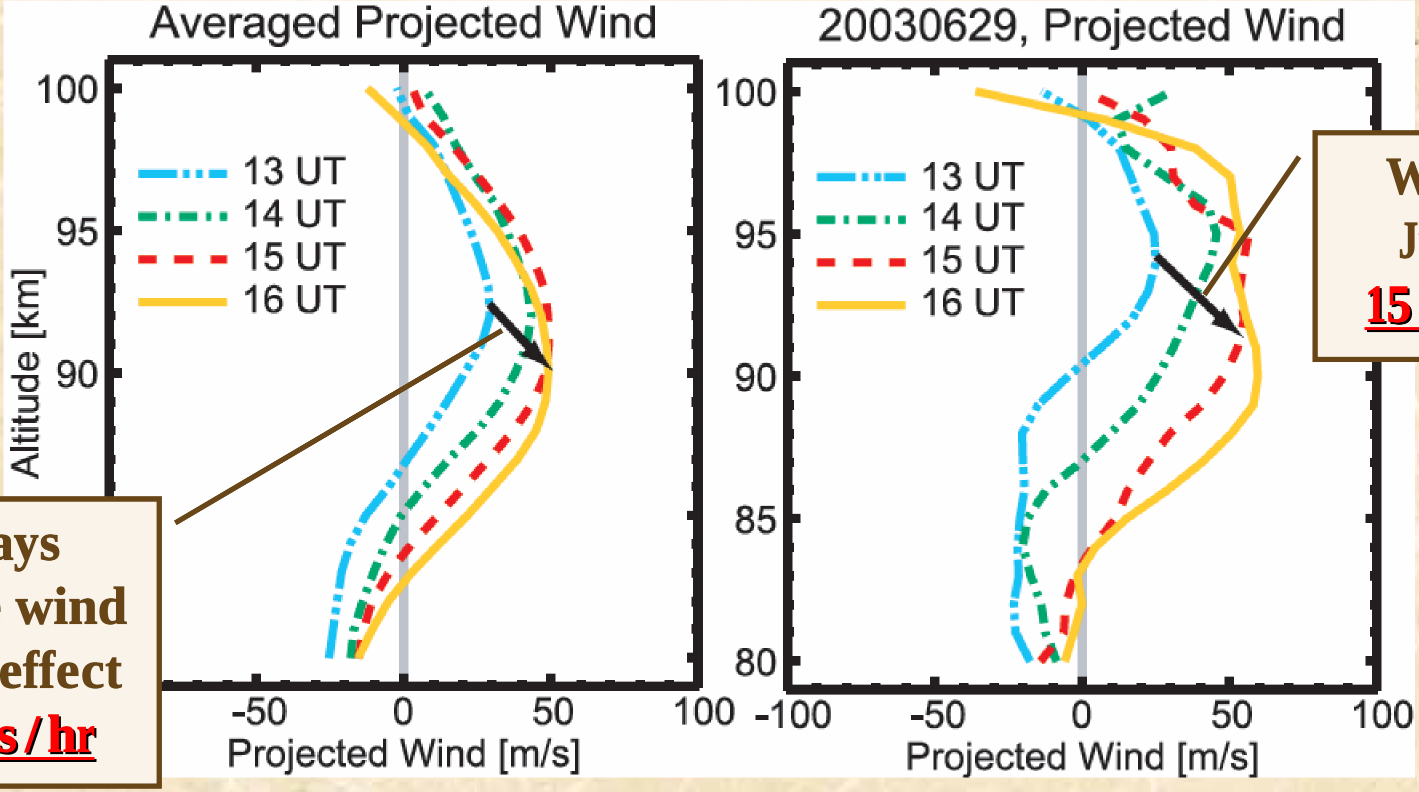
Vertical wavelength

↓

decreases

Average F_M ~7 m^2/s^2

Effects of Wave Dissipation on Background Winds?



30 days
average wind
~ tidal effect
<u>**10 m/s/hr**</u>

Wind on
June 29
<u>**15 m/s/hr**</u>

- **Wind change caused by the wave dissipation:**
  - **$\Delta u = F_M \times \Delta t \; / \; H \sim 5.8$ m/s/hr** [Fritts et al., 2002]

Wave dissipation Δu at the CL ~ 50% of Tidal Δu

Conclusion 2

- The GW dissipation was caused by wind filtering at a strong critical level (CL) that was generated by downward phase progression associated with the diurnal tide.
- The observed GW-CL interaction impacted the background wind (resulting in an acceleration), but not the background temperature (not shown).
- Comparison of acceleration due to the diurnal tide and due to GW dissipation at the CL suggests that F_M from short-period GWs (as observed by the MTM) has the capability to significantly accelerate the background wind field (in this case Δu ~50% of tidal effect).
- In general, the GW-CL interaction is quite an efficient mechanism, not only for wind filtering of GW propagation but also for wind acceleration by dissipating GW.

Acknowledgements

Co-author: Dr. Alan Z. Liu

Co-author: Dr. Steven J. Franke

Co-author: Dr. Dominique Pautet

Colleague: Dr. Yucheng Zhao

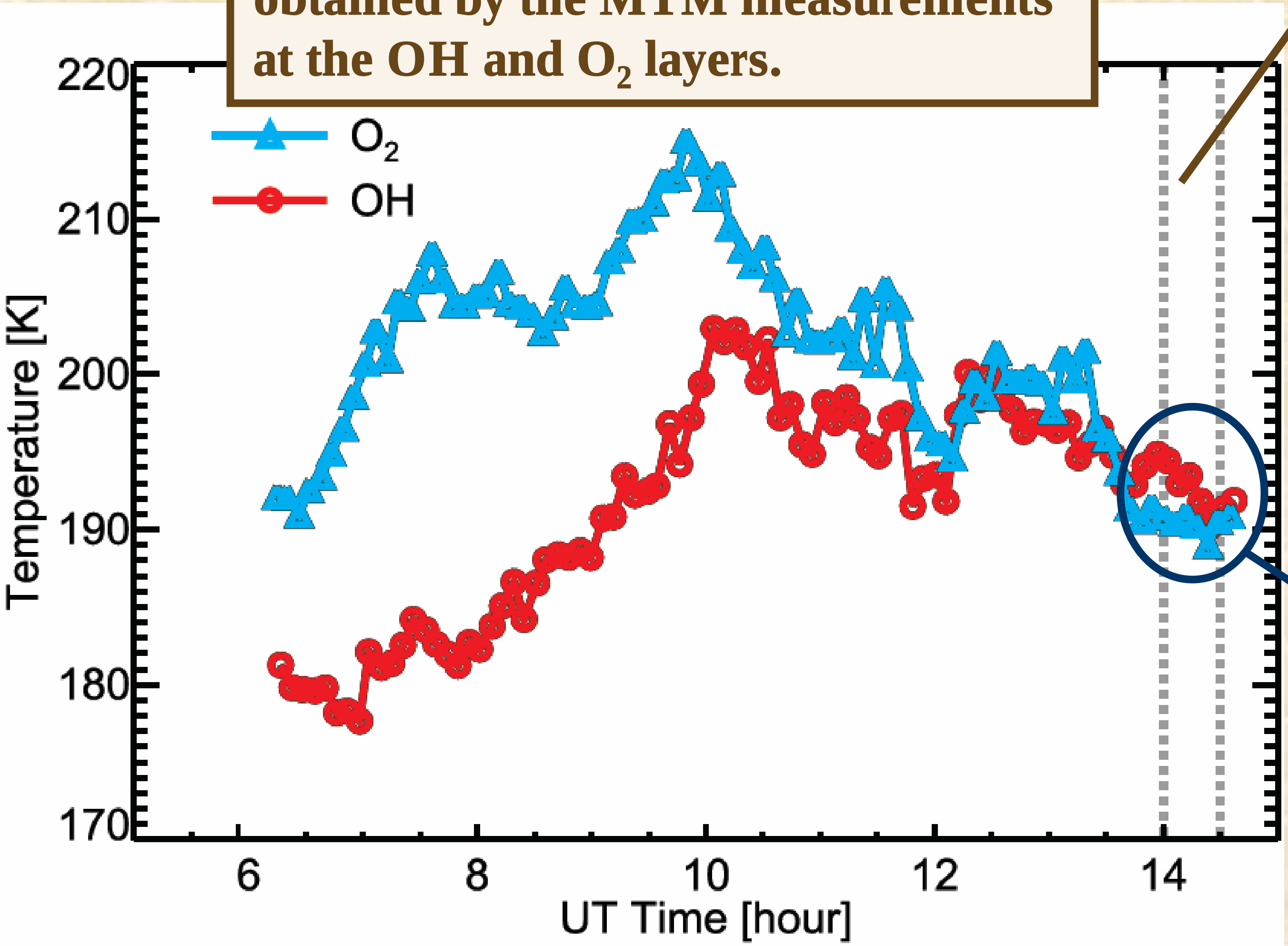
Colleague: Dr. Bill Pendleton

Advisor: Dr. Michael J. Taylor

Utah’s sky

Effects of Wave Dissipation on Background Temperature?

Zenith temperature variation obtained by the MTM measurements at the OH and O_2 layers.

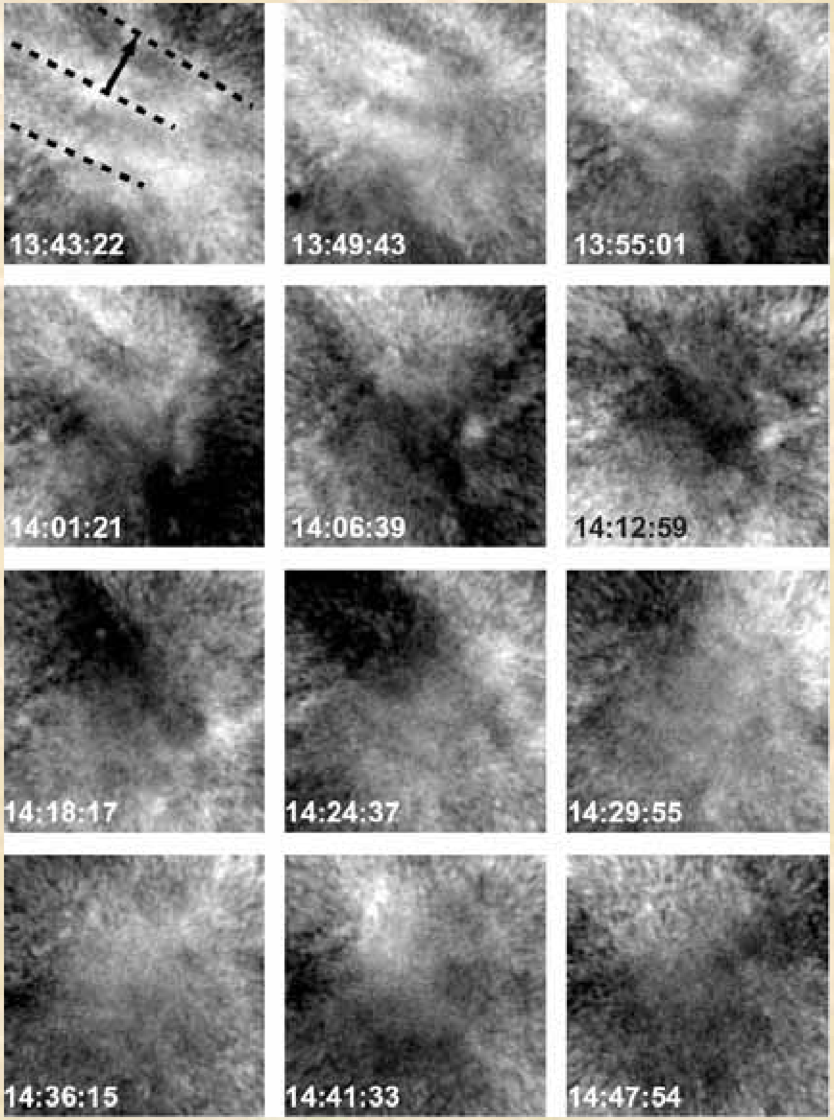


Critical Level Region

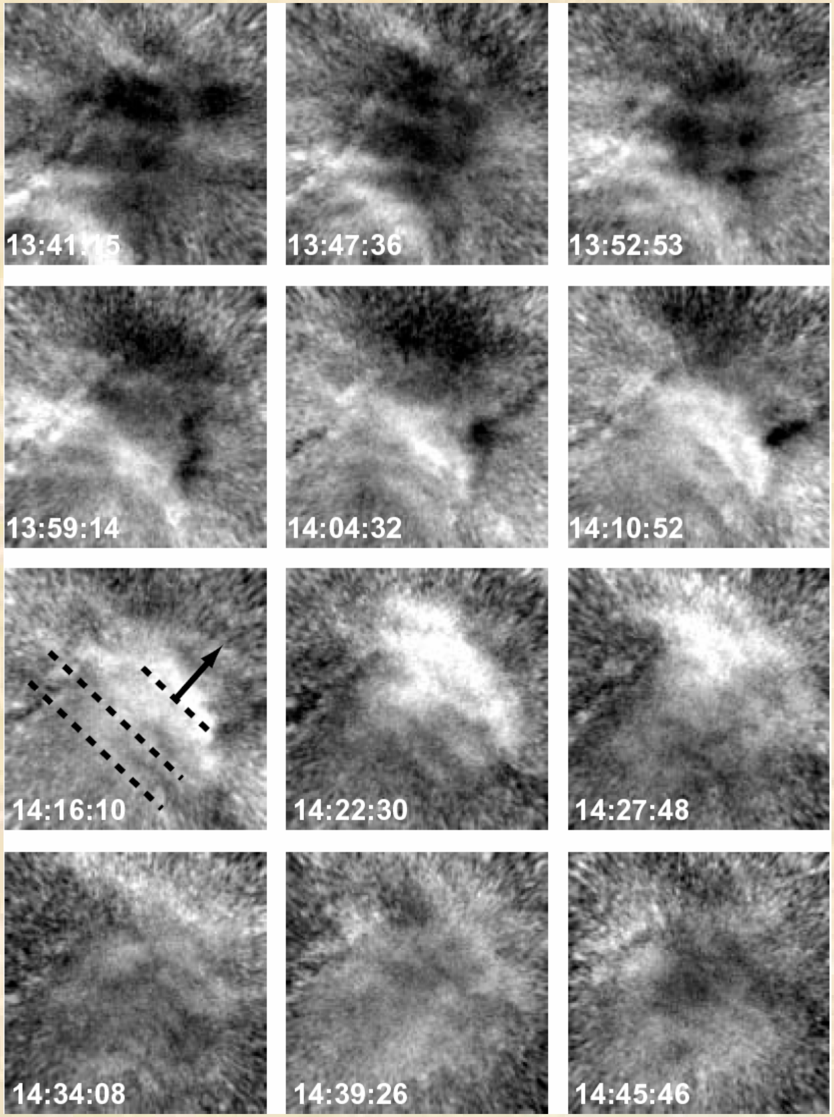
No significant change

Critical Level Event

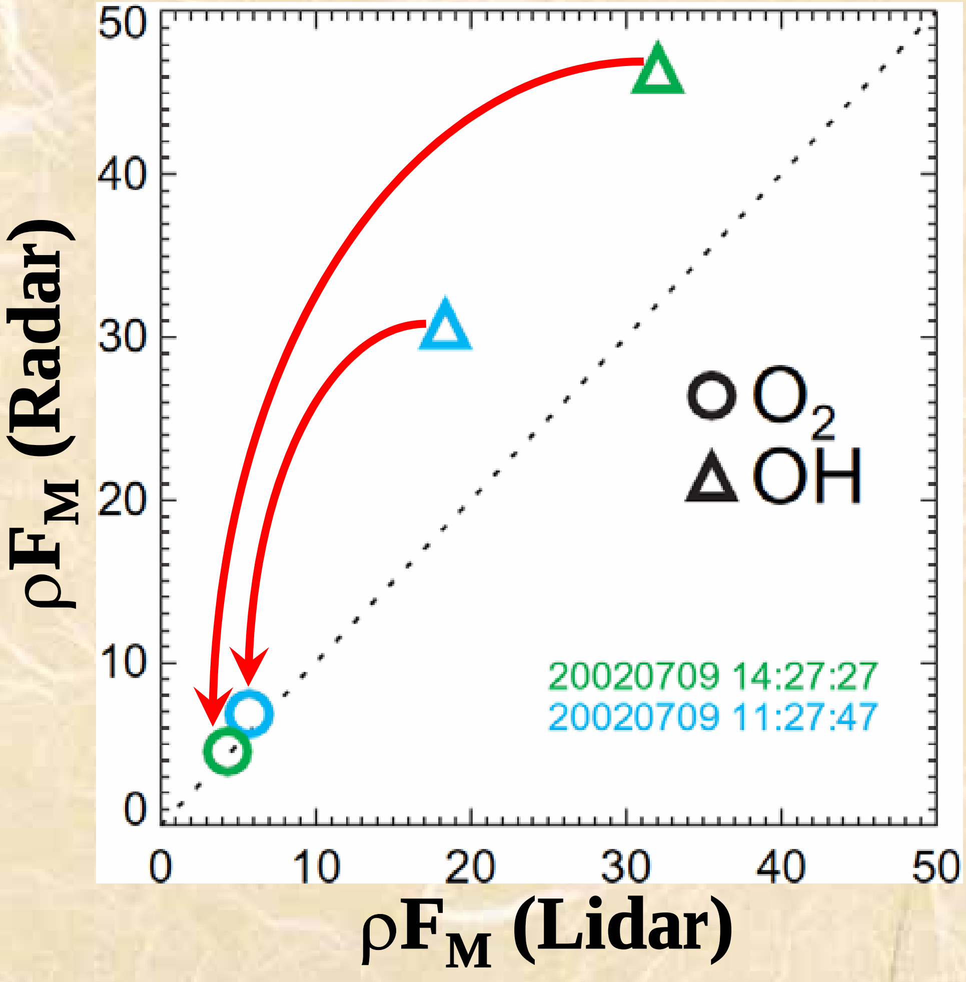
- O_2



- OH



Comparison of ρF_M between OH and O_2



→ GW lose F_M during upward propagation.

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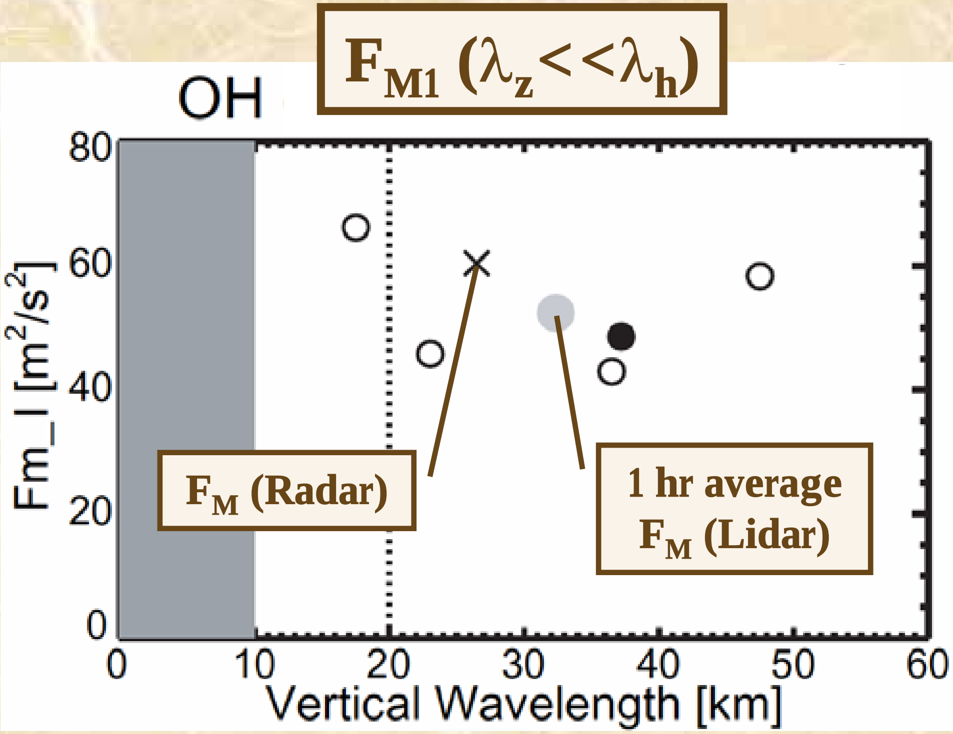
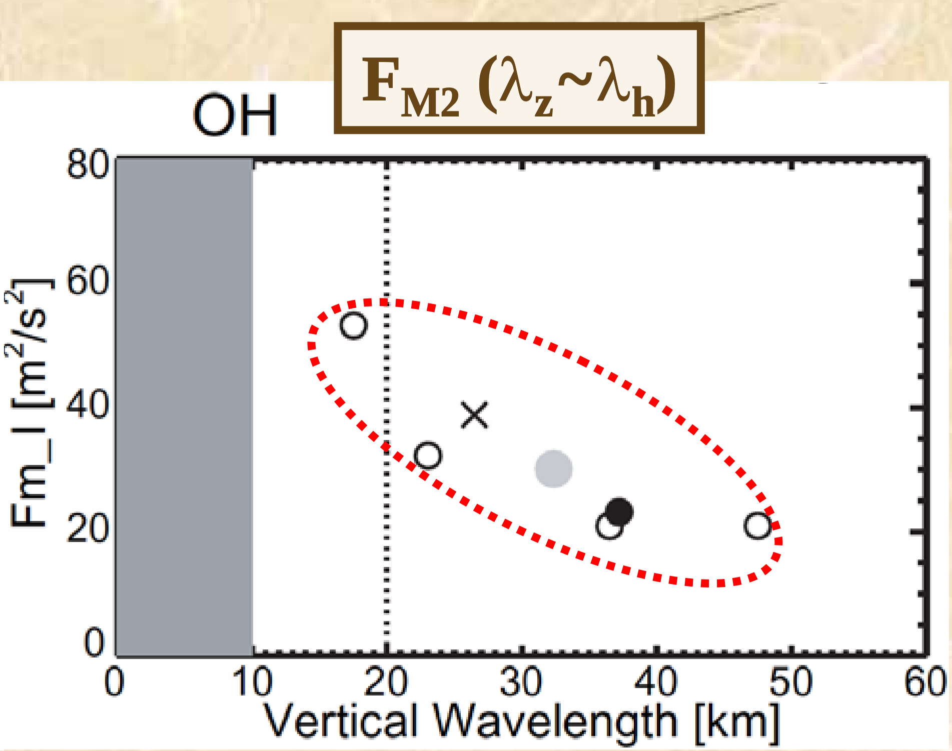
F_M Results (Event #1)





F_{M1} ~ 45-60 m^2/s^2

F_{M2} ~ 20-40 m^2/s^2

- F_M(Radar) ≈ 1 hr average F_M(Lidar)