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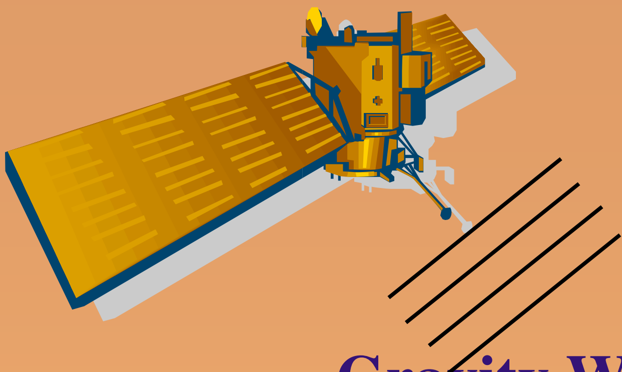

Gravity Wave Propagation from the Ground to the Thermosphere: Initial Results from the FOREGRATS Model

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The Current Situation

• An effect that occurs in the nighttime equatorial region, now known as ESF, disrupts radio communications, particularly the L-band (~1 GHz, ~VHF and microwave) and surrounding communication/navigation frequencies. This 'disruption' is in the form of radio scintillation, an effect caused by the loss of coherency of the radio wave phase fronts due to the scattering off of irregularities that are dependent on the radio wavelength (similar to the scintillation of starlight leading to 'twinkling'). Power loss is ~10 dB.

• The basic physical mechanisms that cause ESF are generally well-known, and DSP measures can be taken to account for the signal degradation.

HOWEVER: The community still cannot forecast the occurrence of ESF. So, we try to understand the atmospheric conditions that cause its occurrence:

1) Measure horizontal wind amplitude, zonal E-polarization field strength, status of E-dynamo, gradient in electron density concentration, etc. **=> Drivers or pre-conditioners?**

2) [Purpose of this study] Try to better understand any gravity wave "seeding" mechanisms. Specifically, to investigate the possibility that such waves originating from the lower and middle atmosphere can impact the thermosphere.

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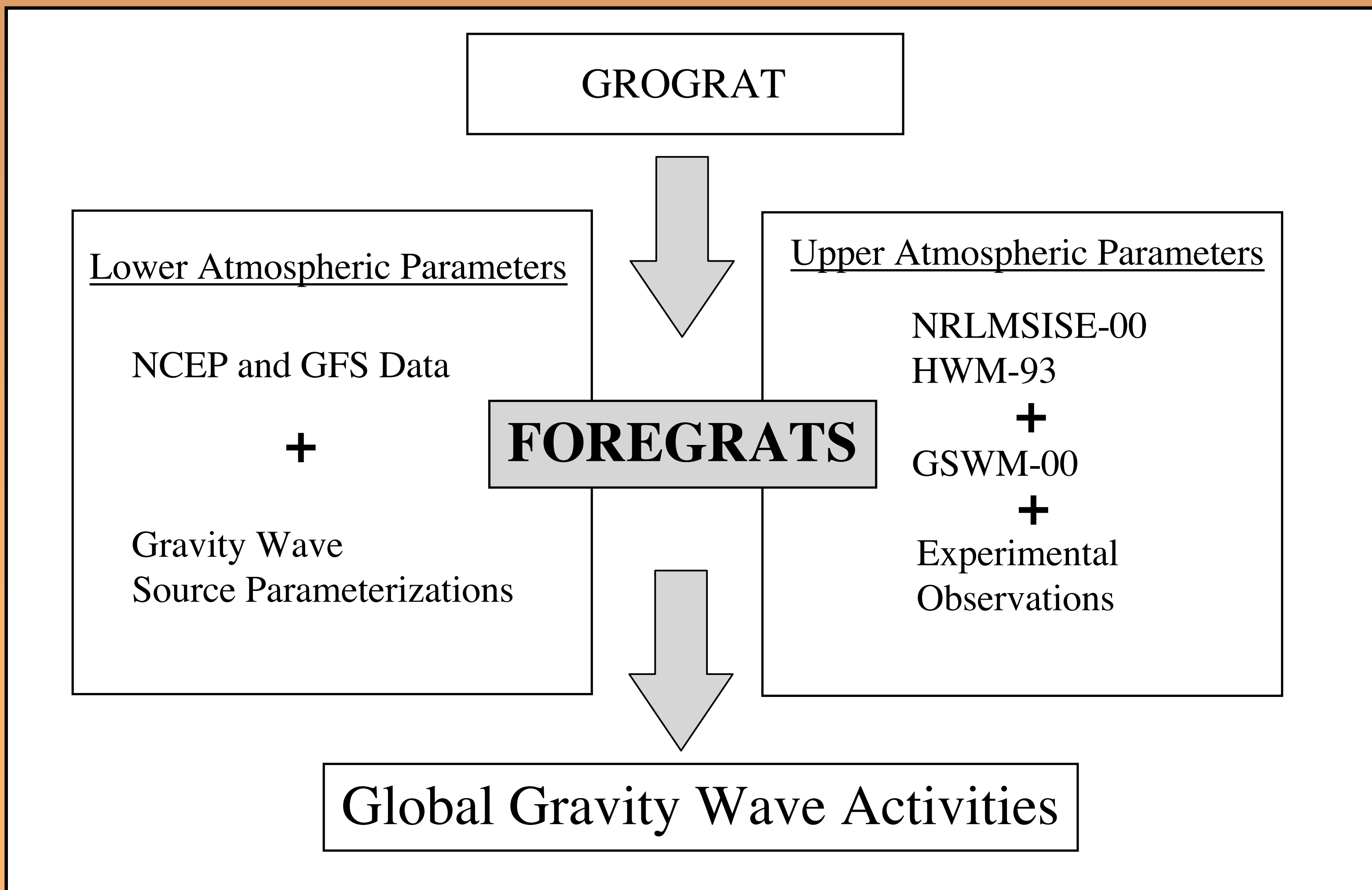
FOREGRATS

(FORECasting of Gravity waves via Ray-tracing Algorithms with prescribed Tropospheric Sources)



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GROGRAT (Gravity Wave Regional or Global Ray Tracer)

- A ray-tracing model that tracks the propagation and amplitude evolution of gravity waves through the lower and middle atmosphere [Steve Eckermann, NRL].

- Wave amplitudes are tracked along ray paths using wave action conservation methods, subject to dissipation due to scale-dependent infrared radiative damping [*Zhu*, 1993], turbulent diffusion [*Pitteway and Hines*, 1963] and saturation due to convective/dynamical instabilities [*Fritts and Rastogi*, 1985].

- Computed ray paths are fully three-dimensional and include wavenumber refraction due to both horizontal and vertical gradients in the background atmosphere. WKB violations are flagged due to waves that reflect vertically near turning points or encounter critical levels.

With GROGRAT backbone, we reconfigured its operational code to
1) identify gravity wave sources and prescribe a source spectrum, and
2) trace gravity waves through the middle atmosphere across the entire globe

for example…

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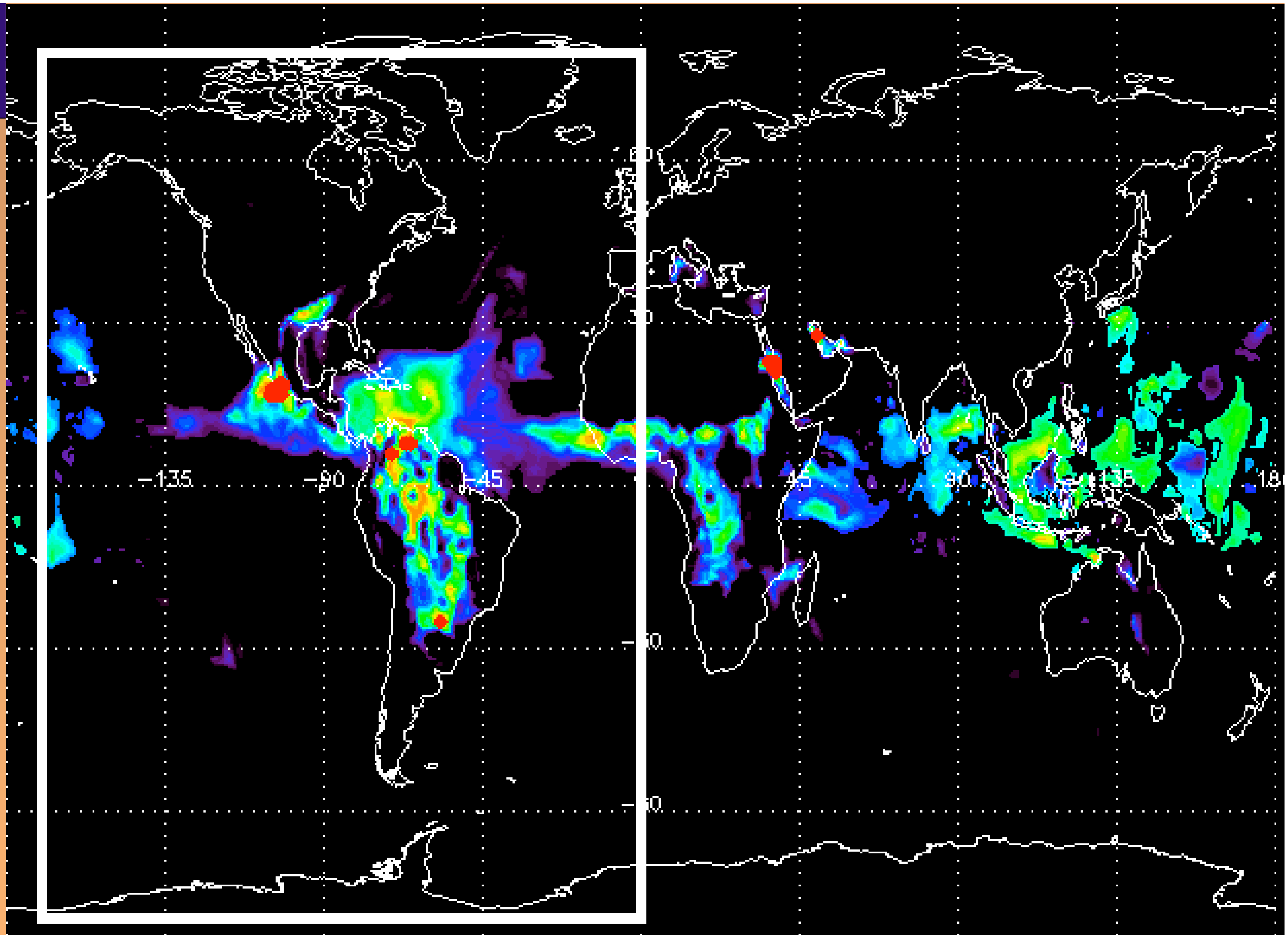
Operational Example of Lower and Middle Atmospheric Gravity Wave Forecasts

“Halloween Run”
Oct 31, 2004
[not 2003…]
12 UT



Global map of CAPE. Scale ranges linearly from black (= 0 J/kg) to blue to green to yellow to red (= 3500+ J/kg). American-sector FOREGRAT model domain (white boundary) and the locations of the identified convective sources (red dots).

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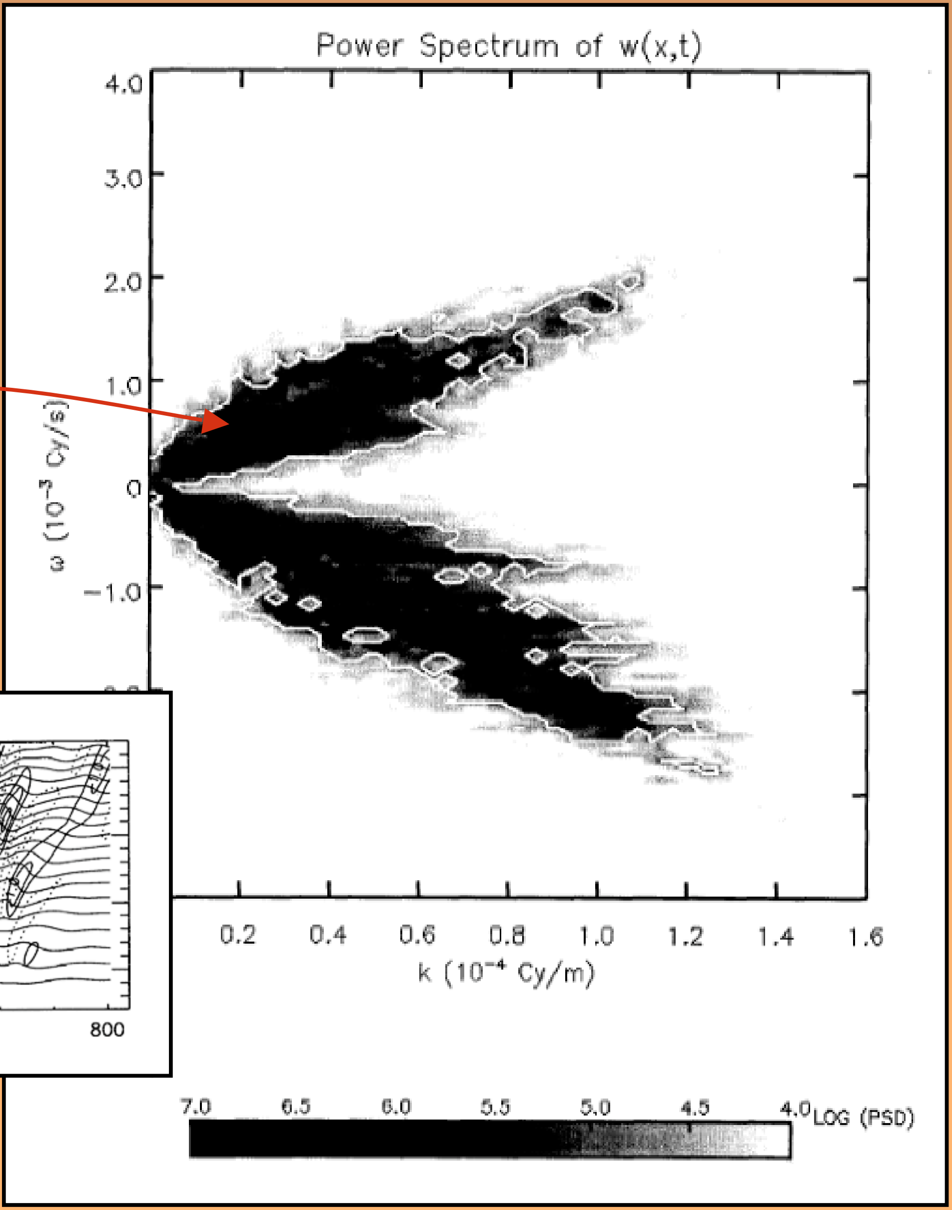
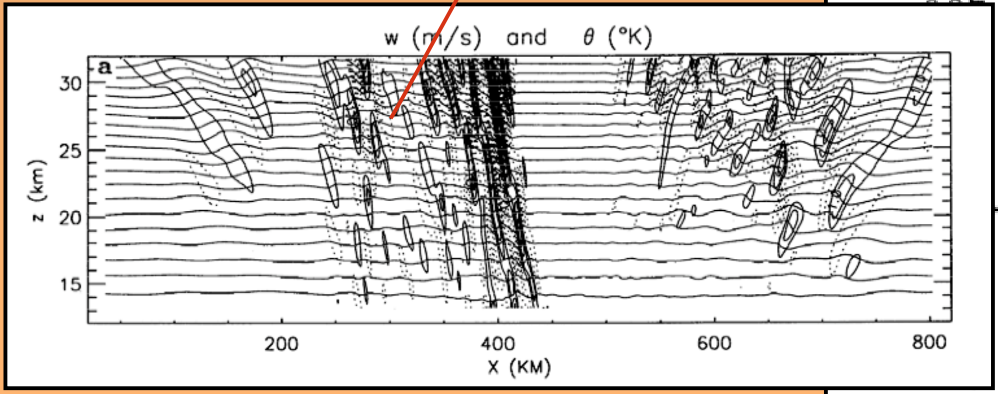
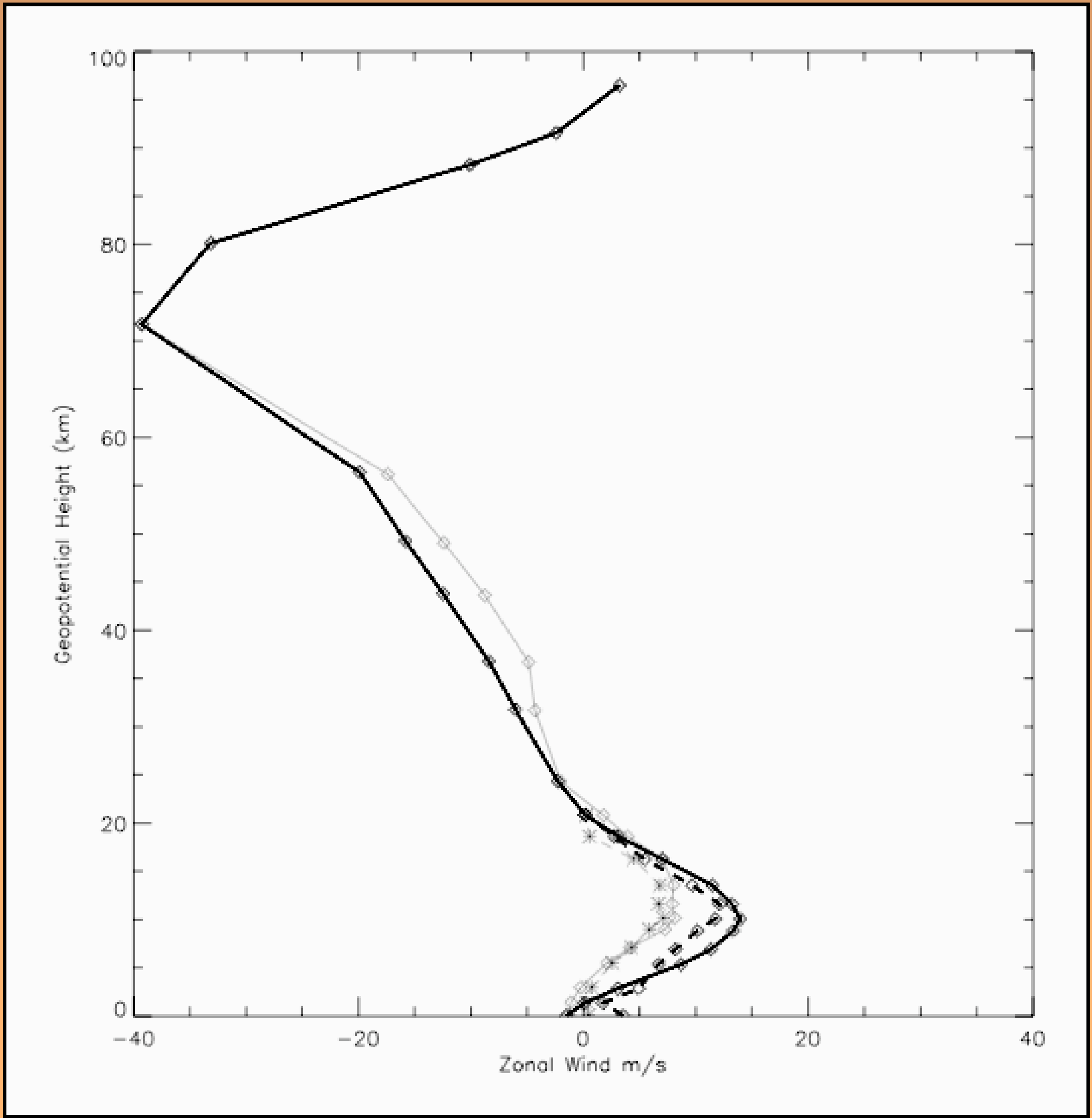
Define Gravity Wave Source Spectrum…

TOUGH!!!





[Alexander, 1996]



Prescribe a Synoptic, Gridded Background Atmosphere

- •NCEP geopotential height and temperature fields
- •NCEP Global Forecast System (GFS)
- •ECMWF analyses
- •CIRA-86
- •NRLMSISE00
- •HWM-93
- •GSWM-00

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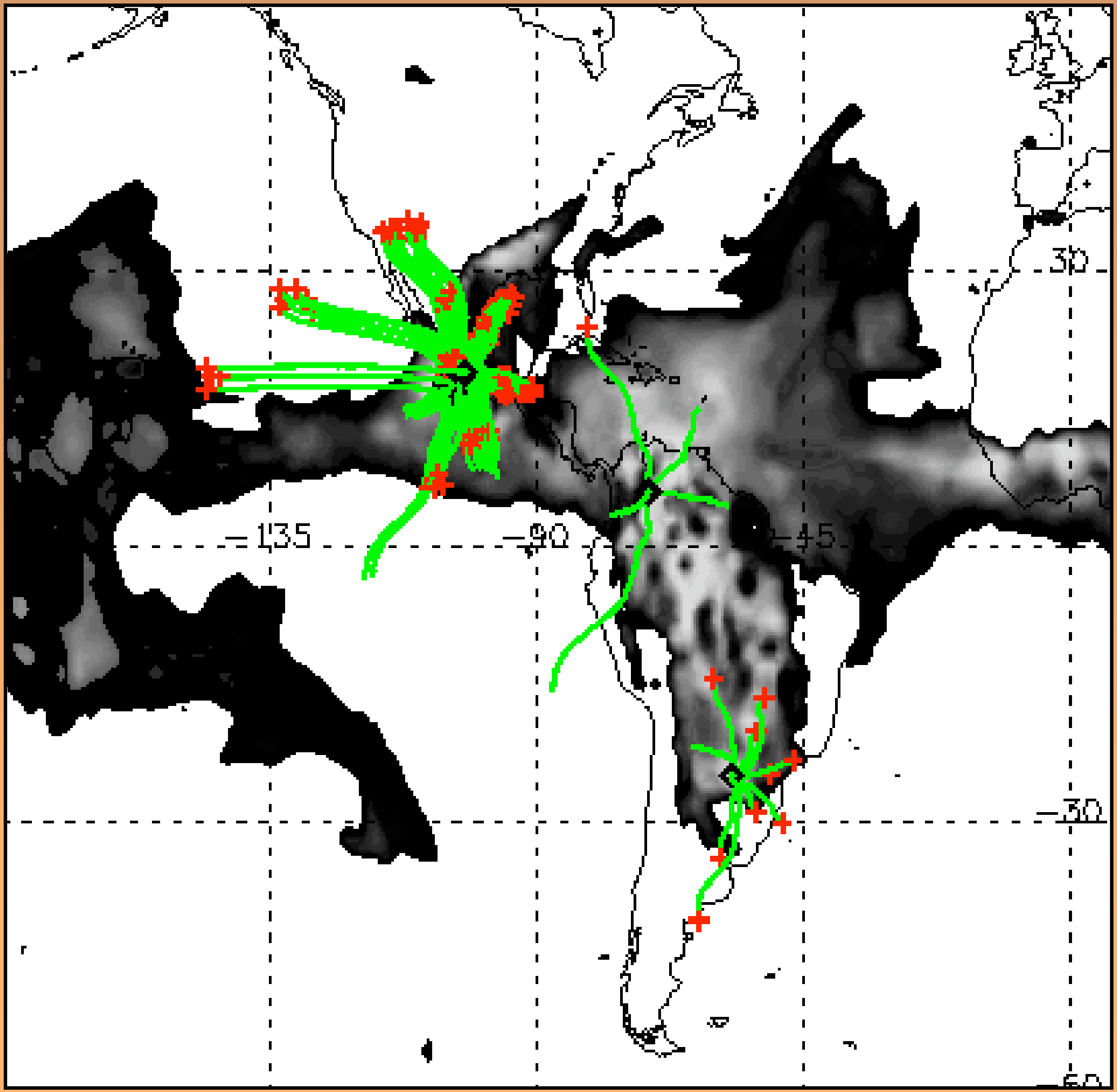
Output

Gravity wave ray-tracing results. Green lines are ray traces, and gravity waves that reached 100 km have a red '+' at the end.



NOW ASK:
Can these waves propagate over 100 km?

Run FOREGRATS in a diagnostic mode…

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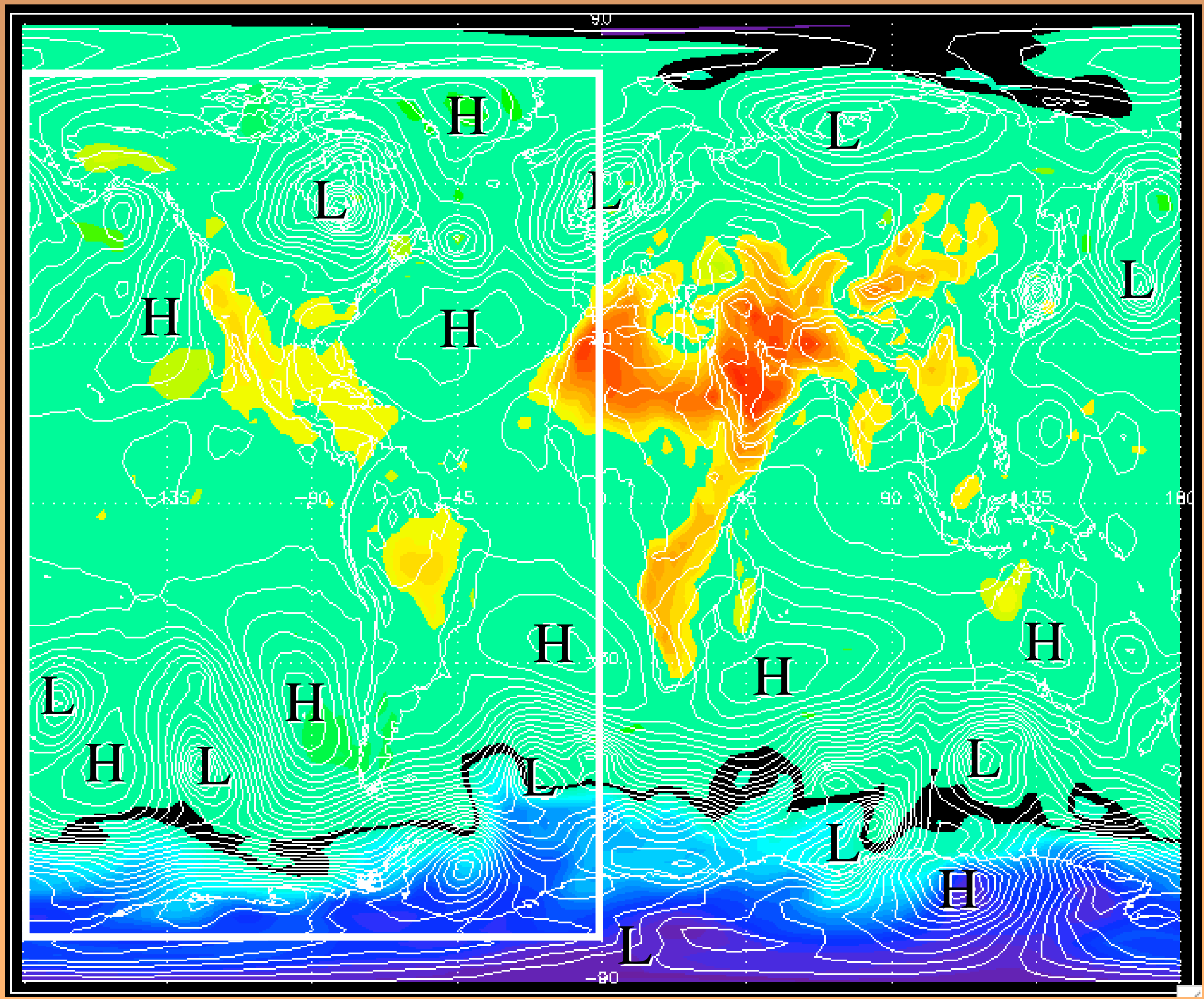
Synoptic Background Atmosphere

Geopotential height (contours) and Temperatures (color) at 925 mbar on August 19, 2004 from ECMWF analyses

H and L mark highs and lows, respectively.

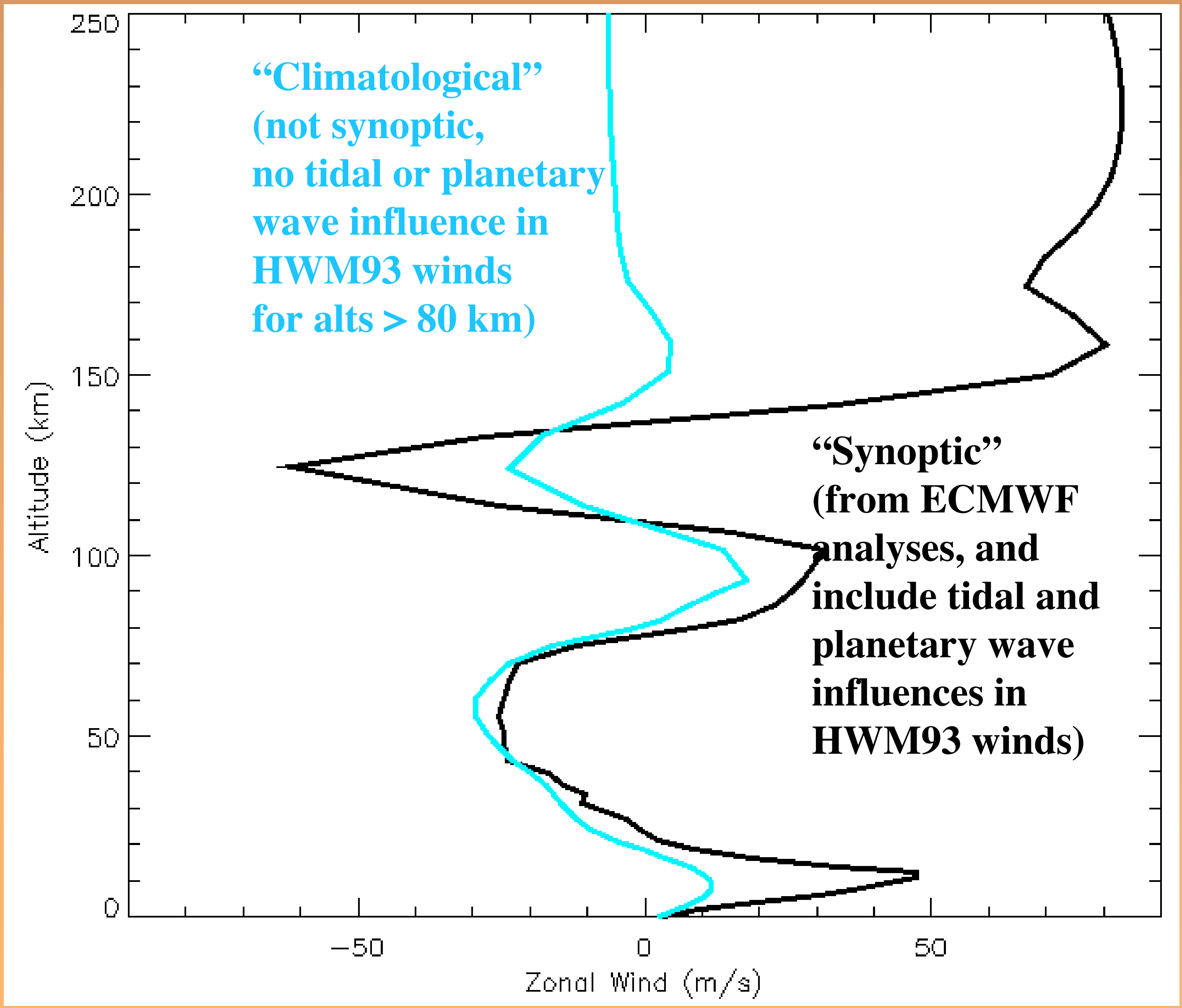
Western hemisphere FOREGRATS model domain is marked by a white rectangular box.



Wind Schemes

Wind profiles vary greatly depending on the choice of data.

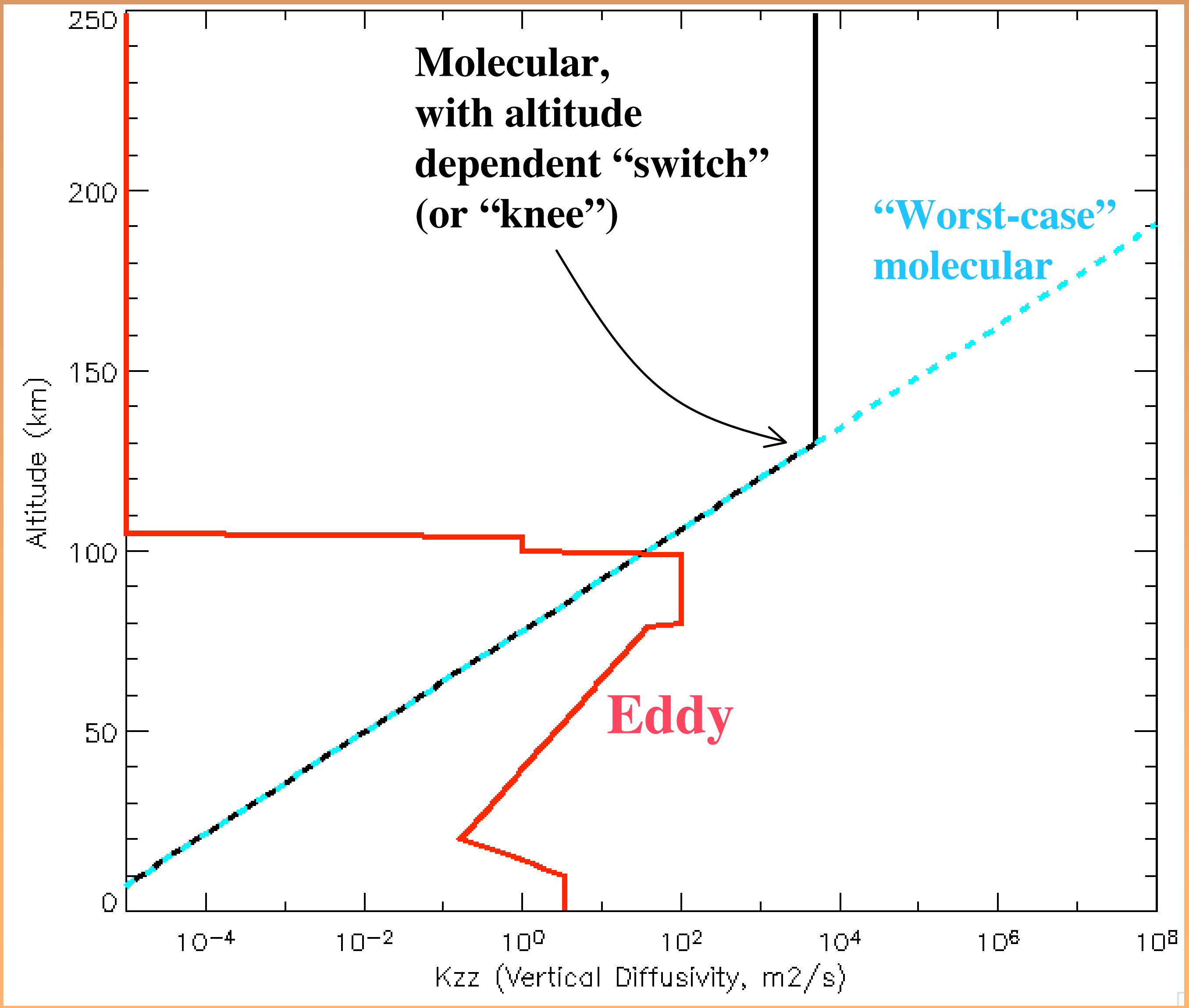
For example, lower thermospheric jets, whose strong vertical shears can vary m, are much weaker without tidal influence.



Vertical Diffusivity Schemes

FOREGRATS now uses a vertical damping parameterization based on both eddy and molecular diffusivity AND a radiative damping parameterization.

Here, we show some of the various diffusivity schemes.



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FOREGRATS Configuration

a) synoptic backgrounds
b) worst-case molecular diffusivity
c) eddy diffusivity

⇒1279 gravity waves were launched [arbitrarily] at ± 45° latitude at 180° longitude at an altitude of 10 km.

⇒ Horizontal wind amplitudes were all initially set to 0.1 m/s.

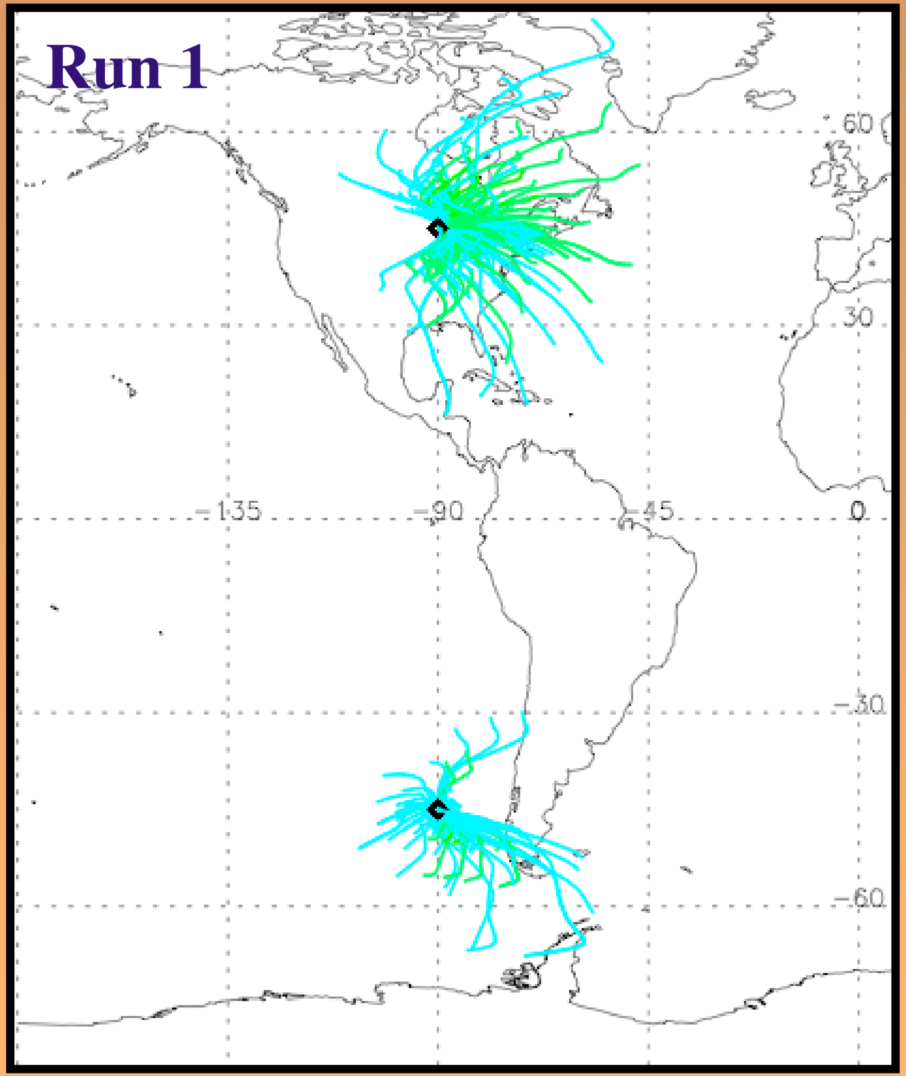
⇒ Model was stopped after 12 hour run.

⇒ Full distribution of all possible gravity waves with the parameters:

•*Tint* of 4, 2, 1, 0.5, and 0.25 hours

•λ_x and λ_y, of ∞, 1024, 512, 256, 128, 64, 32, and 15 km

•RESULTS DISCUSSED IN RUN 2, BELOW



Waves terminated at:

60 or 100 km | 140 km | 180 km

FOREGRATS Configuration

a) synoptic backgrounds
b) molecular diffusivity knee at 130 km
c) eddy diffusivity

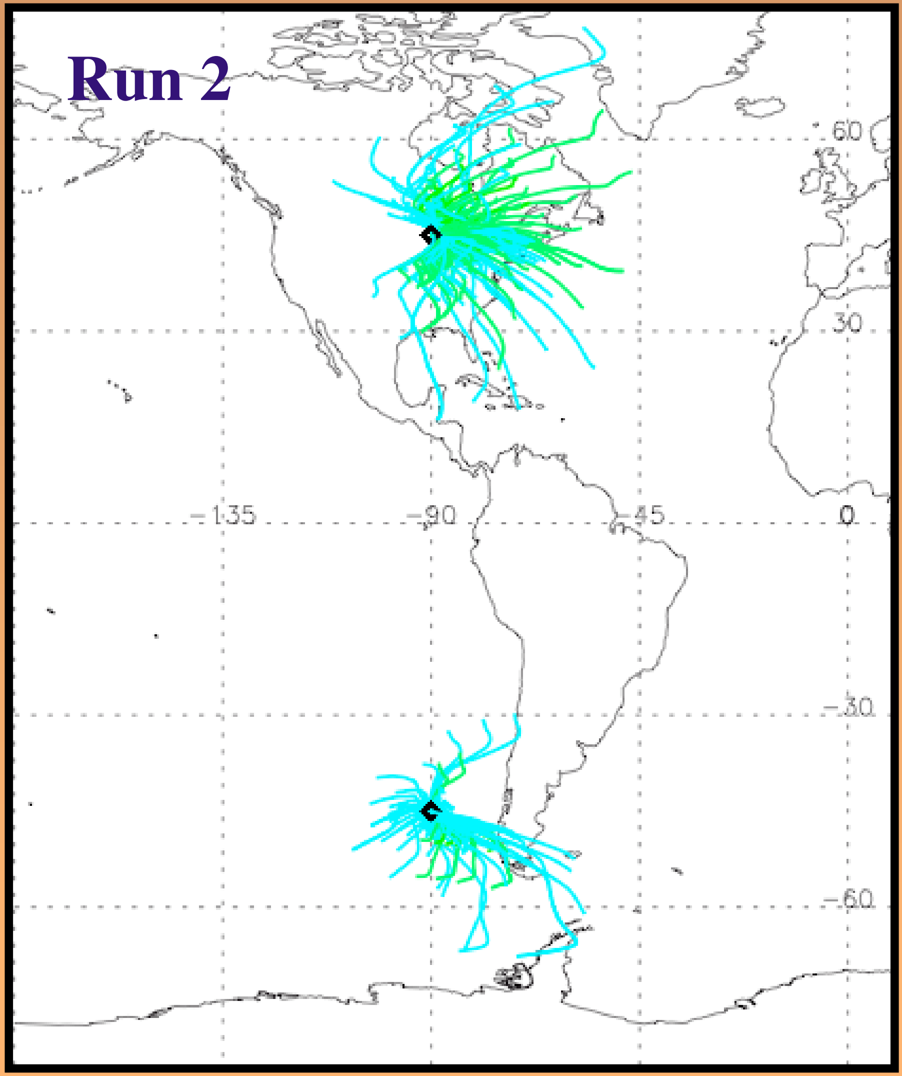
- RESULTS IDENTICAL TO RUN 1, NO WAVES REACHED 180 KM, AND VERY FEW REACHED 140 KM

- ZONAL, MERIDIONAL, AND VERTICAL REFRACTION ARE VERY IMPORTANT

- MOST WAVES WERE DISSIPATED BY COMBINED MOLECULAR AND EDDY DIFFUSION BELOW 130 KM (see next run)

- WKB VIOLATION WAS IMPORTANT, AFFECTING 25% OF WAVES

- WAVES REACHING 140 KM HAD SHORT HORIZONTAL WAVELENGTHS (40-150 km) AND SHORT PERIODS (20-40 min), INDICATING THAT RADIATIVE DAMPING WOULD BE LESS IMPORTANT AT HIGHER ALTITUDES



Waves terminated at:

60 or 100 km | 140 km | 180 km

FOREGRATS Configuration

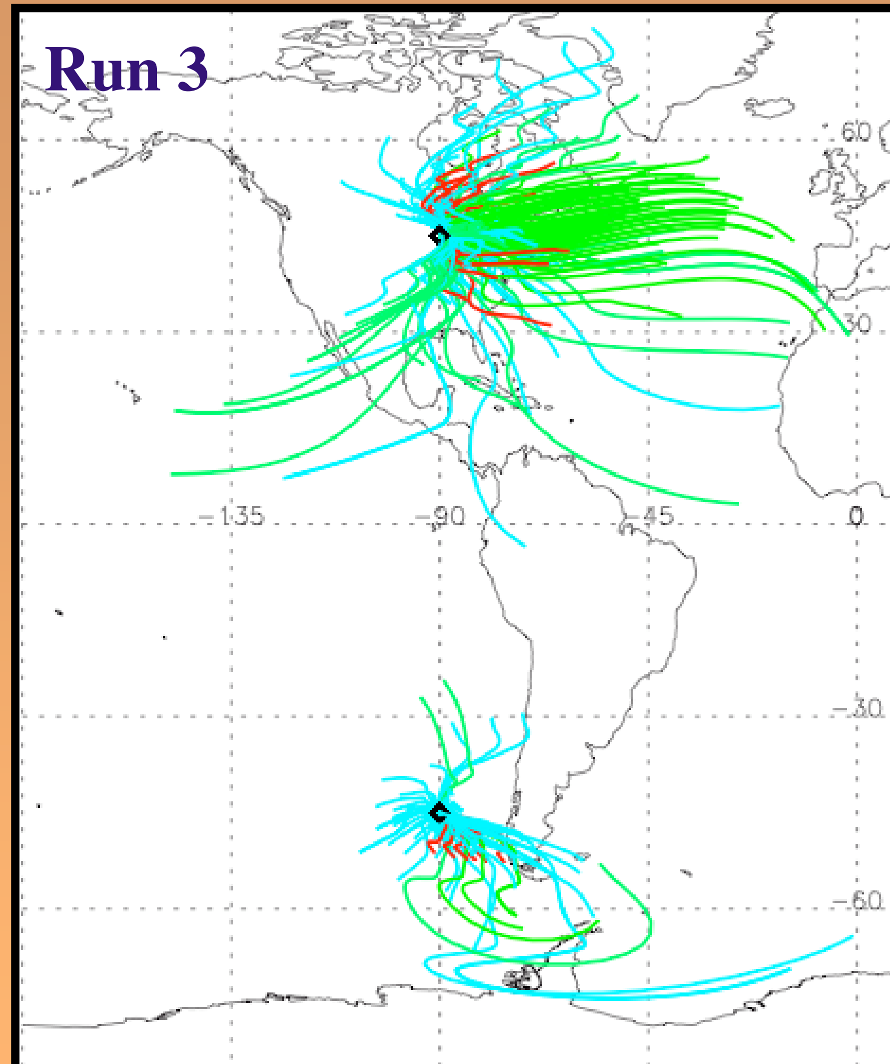
a) synoptic backgrounds
b) NO molecular diffusivity
c) eddy diffusivity

• WAVES REACHED 180 KM, AND GREATER NUMBER REACHED 140 KM

• WAVES AT 140 KM HAD A LARGER SPREAD OF HORIZONTAL WAVELENGTHS COMPARED TO RUNS 1 AND 2

• STRUCTURE OF MOLECULAR DIFFUSIVITY PROFILE IMPORTANT
⇒ TEMPERATURE OF THERMOSPHERE A KEY FACTOR! WE NEED TO ADDRESS THE TRADEOFF BETWEEN THE BRUNT-VISALLA FREQEUNCY AND INCREASED DIFFUSIVITY

• MOST WAVES WERE DISSIPATED BY EDDY DIFFUSION AND WKB VIOLATION WAS AGAIN IMPORTANT



Waves terminated at:

60 or 100 km | 140 km | 180 km

FOREGRATS Configuration

a) climatological backgrounds

b) molecular diffusivity knee at 130 km

c) eddy diffusivity

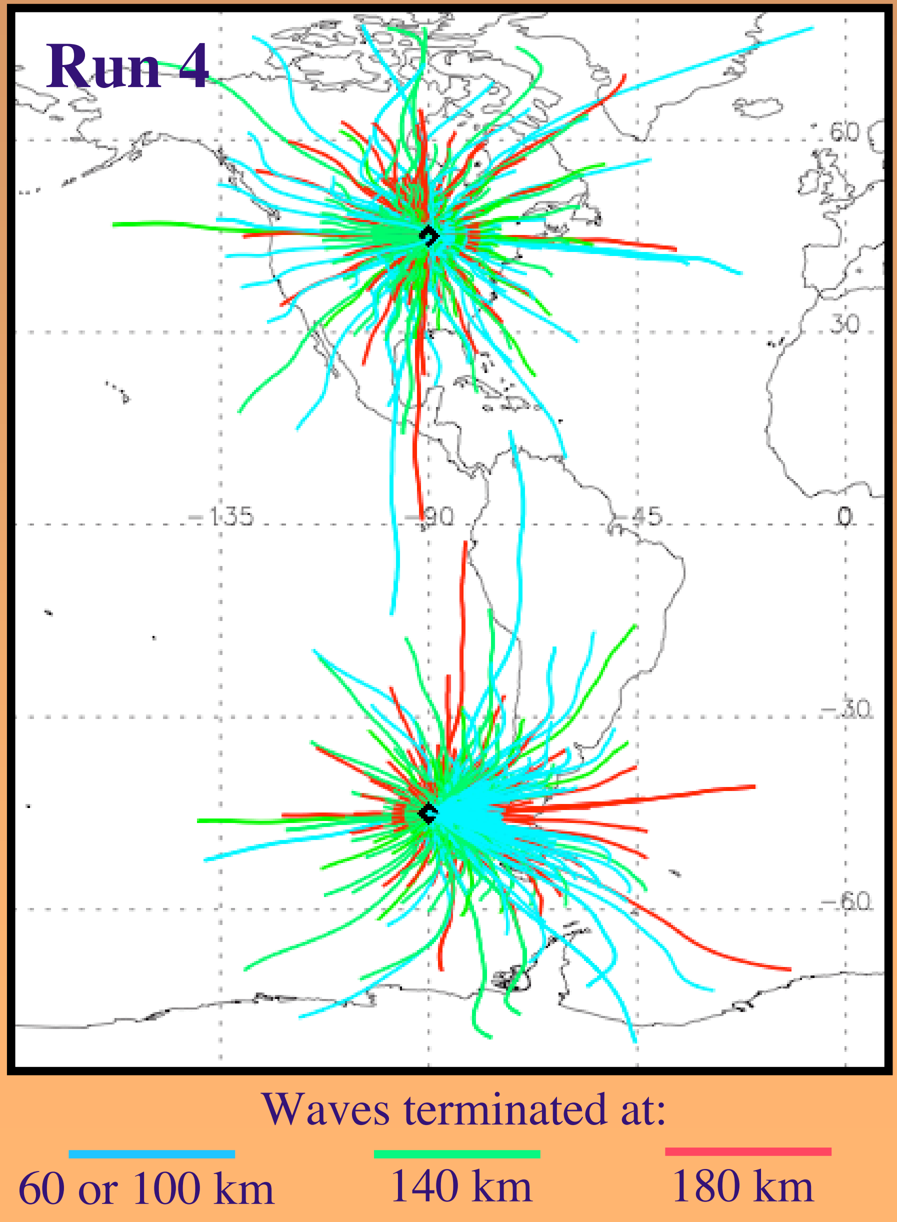
- MANY WAVES REACHED 140 AND 180 KM

- MOST WERE DISSIPATED BY MOLECULAR DIFFUSION, AND WKB WAS NOT IMPORTANT

- THIS RUN HAD THE GREATEST SPREAD OF VERTICAL WAVELENGTHS AT 140 KM

- INDICATES THAT LOWER AND MIDDLE BACKGROUND WIND REFRACTION IS ESSENTIAL IN FILTERING THE OVERALL GRAVITY WAVE SPECTRUM.

⇒ SYNOPTIC ATMOSPHERIC CONDITIONS ARE NEEDED!



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Conclusions

•We show that tropospherically generated gravity waves can, in theory, propagate into the lower thermosphere. However…

•The temperature of the thermosphere will affect if these waves can propagate further upwards. This is because the the temperature affects the molecular diffusivity which severely damps long period/short vertical wavelength gravity waves.

•In order to forecast the gravity wave seeding of ESF, synoptic conditions of the lower, middle, and upper atmosphere are required. This is the biggest hindrance, to date, of such methodologies.

•The use of linear ray-tracing methodologies with synoptic atmospheric backgrounds may ultimately prove unviable, given the impact of WKB violation.

•As applied herein to the prediction of ESF, the FOREGRATS model, as constrained by experimental measurements, will increase our understanding of ESF generation, gravity wave generation and propagation, and data assimilation of mesospheric–lower thermospheric synoptic variables.